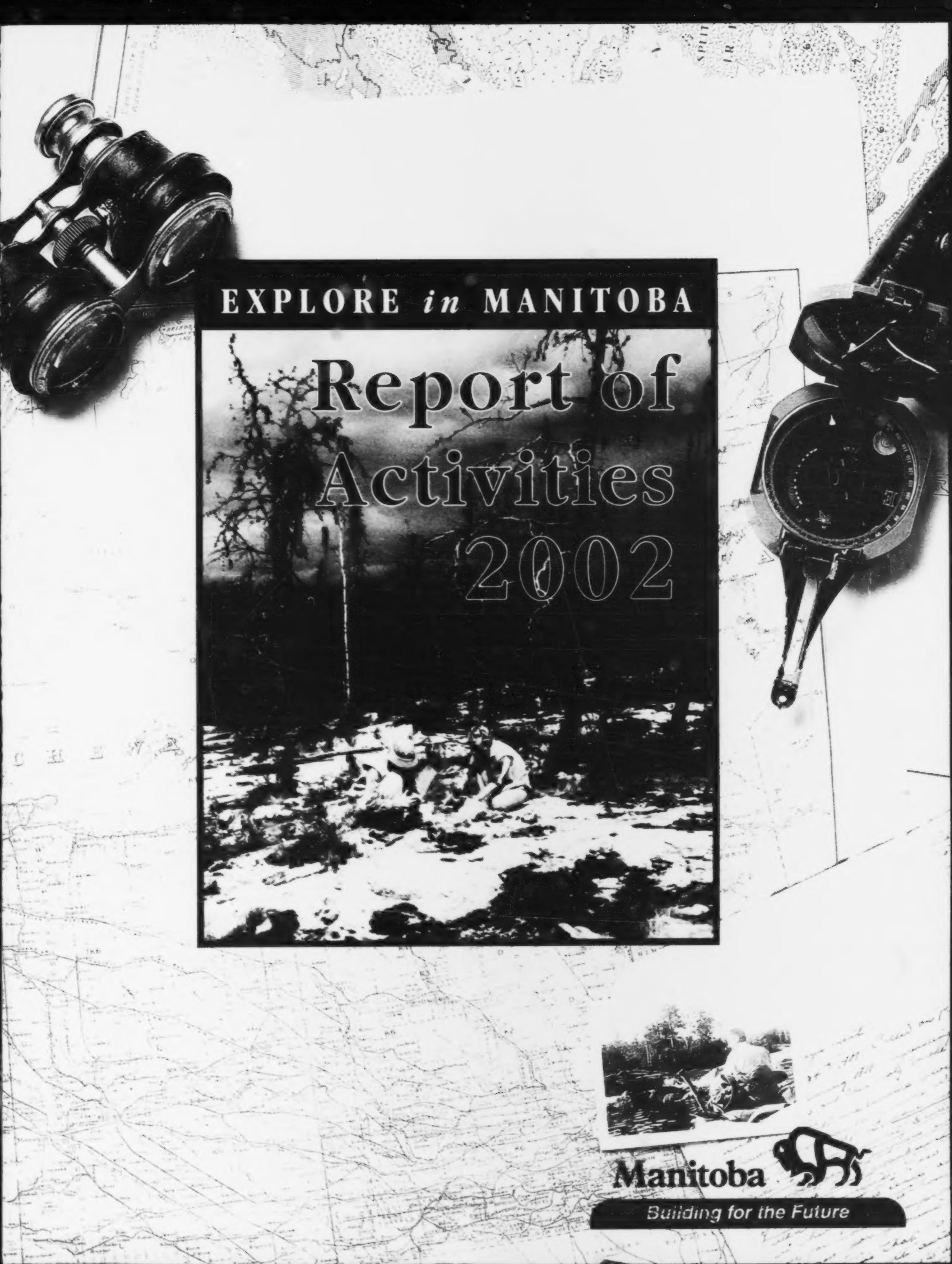


EXPLORE *in* MANITOBA

Report of Activities 2002

Manitoba

Building for the Future

MANITOBA INDUSTRY, TRADE AND MINES

MINISTER, Hon. MaryAnn Mihychuk
Room 358, Legislative Building
Winnipeg MB R3C 0V8
(204) 945-0067 Fax: (204) 945-4882

DEPUTY MINISTER, Hugh Eliasson
Room 352, Legislative Building
Winnipeg MB R3C 0V8
(204) 945-4076 Fax: (204) 945-1561

MINERAL RESOURCES DIVISION

360 - 1395 Ellice Avenue, Winnipeg MB R3G 3P2
minesinfo@gov.mb.ca
Toll-Free (in North America) **1-800-223-5215**
www.gov.mb.ca/itm/mrd

ASSISTANT DEPUTY MINISTER, Christine Kaszycki
(204) 945-4317 Fax: (204) 945-1406

MANITOBA GEOLOGICAL SURVEY

Fax: (204) 945-1406

Director	Ric Syme	945-6556
Geoscience Information Services	Paul Lenton	945-6553
Precambrian Mapping Section	Al Bailes	945-6555
Sedimentary and Industrial Minerals Section	Ruth Bezys	945-6563
Mineral Deposits Section	Vacant	
Client Services		
Manager	Monique Lavergne	945-6551
Library	Lori Janower	945-6569
Publication Sales	Elaine Hunter	945-4154
		(Fax) 945-8427

Core Storage, 10 Midland Street, Winnipeg;
Core Shed, Univ. of Manitoba; Rock Storage Facility,
Perimeter Hwy. at Brady Rd.

	Doug Berk	945-6550
		(Fax) 948-2164

Thompson Office:
204 - 59 Elizabeth Road, Thompson MB R8N 1X4

	Jackie Jones	677-6881
		(Fax) 677-6888

Flin Flon Office:
143 Main Street, Flin Flon MB R8A 1K2

	Tom Heine	687-1633
		(Fax) 687-1634

MINES BRANCH

Fax: (204) 945-8427

Director	Ernest Armitt	945-6505
Mining Recording	Sheena Shetty	945-6528
Mining Engineering	Ben Edirmanasinghe	945-6517
Assessment and Exploration	Jim Payne	945-6535

Brandon Office:
340-Ninth Street, Brandon MB R7A 6C2

	Doug Bender	726-7118
		(Fax) 726-6749

Russell Office:
402 Main Street N., Russell MB R0J 1W0

	Jack Adams	773-3343
		(Fax) 773-2411

Flin Flon Recording Office:
143 Main Street, Flin Flon MB R8N 1X4 687-1630
(Fax) 687-1634

MINERALS POLICY AND BUSINESS DEVELOPMENT

Fax: (204) 945-8427

Manager	Gary Ostry	945-6564
Incentives Coordinator	Carol Isfeld	945-6586
Incentives Assistant	Donna Dault	945-0729
Convention Coordinator	Shirley Henrie	945-2691
Promotions Coordinator	Bob Sales	945-6588

PETROLEUM BRANCH

Fax: (204) 945-0586

Director	Bob Dubreuil	945-6573
Engineering and Inspection	John Fox	945-6574
Administration and Geology	Carol Martiniuk	945-6570
Digital Information Services	Keith Lowdon	748-4262

Virden Office:
227 King Street West, Virden MB R0M 2C0

	Bruce Dunning	748-4260
		(Fax) 748-2208

Waskada Office:
23 Railway Street, Waskada MB R0M 2E0

	Lorne Barsness	673-2472
		(Fax) 673-2767

All staff can be reached by e-mail. Search the Mineral Resources Division web site staff directory for e-mail addresses.

103-02723/

REPORT OF ACTIVITIES
2002

Manitoba Industry, Trade and Mines
Manitoba Geological Survey

Manitoba
Building for the Future

©Her Majesty the Queen in Right of Manitoba, 2002

Every possible effort is made to ensure the accuracy of the information contained in this report, but Manitoba Industry, Trade and Mines does not assume any liability for errors that may occur. Source references are included in the report and users should verify critical information.

Any digital data and software accompanying this publication are supplied on the understanding that they are for the sole use of the licensee, and will not be redistributed in any form, in whole or in part, to third parties. Any references to proprietary software in the documentation and/or any use of proprietary data formats in this release do not constitute endorsement by Manitoba Industry, Trade and Mines of any manufacturer's product.

When using information from this publication in other publications or presentations, due acknowledgment should be given to the Manitoba Geological Survey. The following reference format is recommended:

Manitoba Industry, Trade and Mines 2002: Report of Activities 2002; Manitoba Industry, Trade and Mines, Manitoba Geological Survey, 325 p.

Published by:
Manitoba Industry, Trade and Mines
Manitoba Geological Survey
360-1395 Ellice Avenue
Winnipeg, Manitoba
R3G 3P2 Canada

Telephone:	(800) 223-5215 (General Enquiry) (204) 945-4154 (Publication Sales)
Fax:	(204) 945-8427
E-mail:	minesinfo@gov.mb.ca
Website:	http://www.gov.mb.ca/itm/mrd

REPORT OF ACTIVITIES 2002

A message from the Minister:

Manitoba has a long and successful history of mining that reflects the province's favourable geology and mineral potential. As global competition for mineral investment increases, access to timely, high-quality geoscience data has become essential to explorationists and investors. New and innovative programs conducted by the Manitoba Geological Survey ensure that industry continues to be provided with the information required to make sound exploration decisions. Through the work of the survey, we continue to help define Manitoba's mineral potential and assist industry in the search for new discoveries.

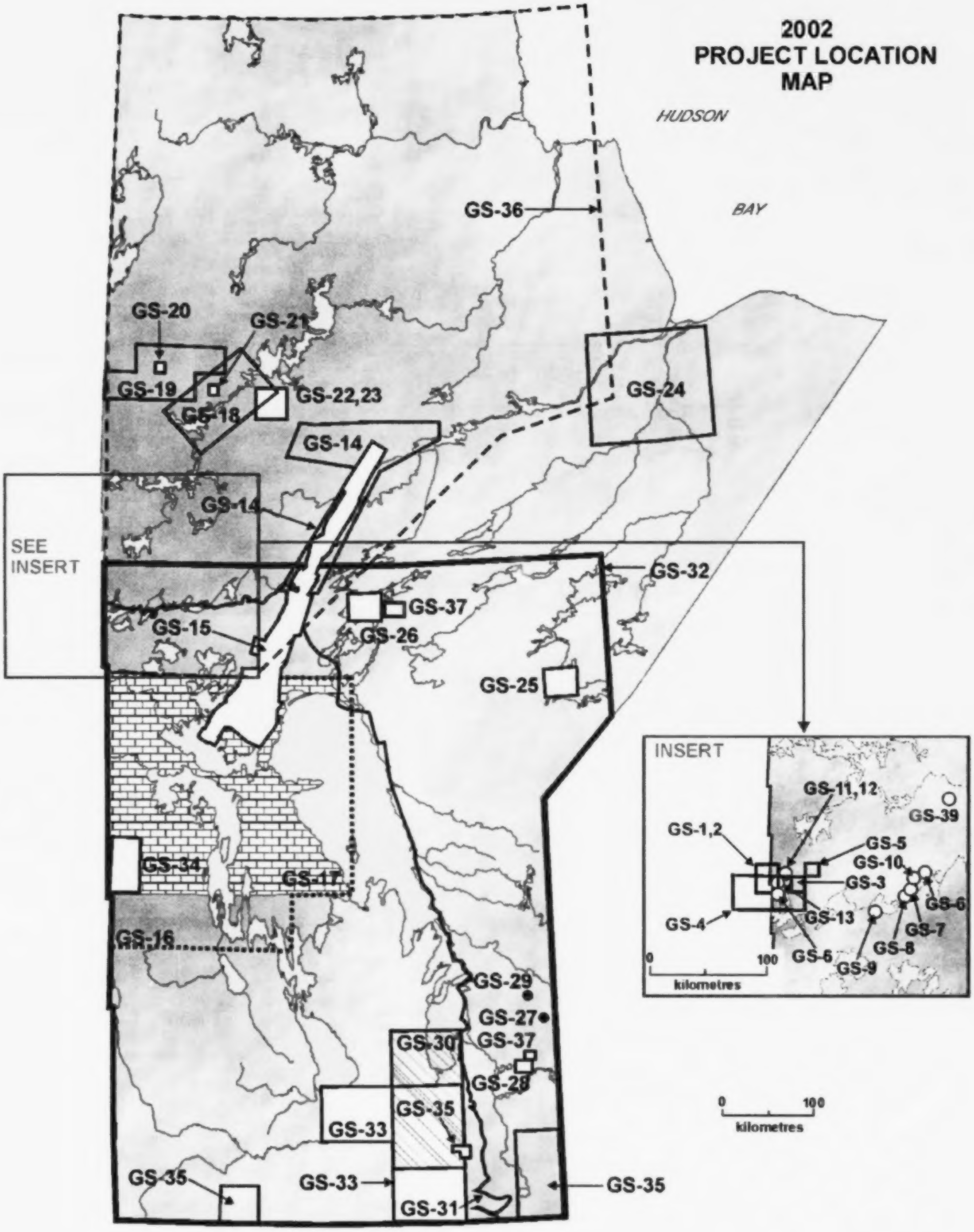
The Report of Activities is a comprehensive summary of geoscience investigations conducted by the Manitoba Geological Survey in the past year. Collaborative projects with the federal government, Canadian and American universities, the mineral exploration industry and various geoscience organizations across Canada are also included.

The Department of Industry, Trade and Mines recognizes the key role played by the mining industry in the provincial economy. We are committed to supporting initiatives that ensure the growth of the industry and the long-term viability of mining communities in Manitoba. The release of this report at our annual Manitoba Mining and Minerals Convention puts some of our most recently acquired geoscience information directly into the hands of current stakeholders and new investors, creating an ideal forum to stimulate discussions and highlight opportunities. The entire Report of Activities is available on our web site and a digital copy on CD-ROM has been included in delegate bags to ensure that the latest on Manitoba geology is readily accessible to everyone.

I hope that the information in this report entices you to invest in one of Manitoba's natural advantages—our mineral wealth.

M. Mihychuk

Honourable MaryAnn Mihychuk
Minister of Industy, Trade and Mines



2002 PROJECT LOCATION MAP

HUDSON
BAY
GS-36
GS-20
GS-21
GS-19
GS-18
GS-22,23
GS-24
GS-14
GS-14
SEE INSERT
GS-32
GS-37
GS-15
GS-26
GS-25
INSERT
GS-11,12
GS-39
GS-1,2
GS-5
GS-10
GS-3
GS-4
GS-13
GS-6
GS-7
GS-8
GS-6
GS-9
0
100
kilometres
GS-34
GS-17
GS-16
GS-29
GS-27
GS-30
GS-37
GS-28
GS-35
GS-33
0
100
kilometres
GS-35
GS-33
GS-31
GS-35

TABLE OF CONTENTS

Minister's Message iii

2002 Project Location Map iv

Annual Review
by E.C. Syme 1

FLIN FLON-SNOW LAKE

GS-1 Stratigraphy of Volcanogenic Massive Sulphide-hosting Volcanic and Volcaniclastic Rocks of the Flin Flon Formation, Flin Flon (NTS 63K12 and 13), Manitoba and Saskatchewan
by C.A. Devine, H.L. Gibson, A.H. Bailes, K. MacLachlan, K. Gilmore and A.G. Galley 9

GS-2 Geology and Hydrothermal Alteration of the Hanging Wall Stratigraphy to the Flin Flon–777–Callinan Volcanogenic Massive Sulphide Horizon (NTS 63K12NW and 13SW), Flin Flon Area, Manitoba
by D.E. Ames, N. Tardif, K. MacLachlan and H.L. Gibson 20

GS-3 Alteration of the Paleoproterozoic Felsic Volcanic Baker Patton Complex (NTS 63K12NE and 13SE), Flin Flon, Manitoba
by D.E. Mitchinson, H.L. Gibson and A.G. Galley 35

GS-4 Trace-Element Signatures of Flin Flon Volcanogenic Massive Sulphide (VMS) Deposits (NTS 63K, 63L), Manitoba
by I.R. Jonasson, A.G. Galley and D.E. Ames 41

GS-5 Geology of the Alberts Lake Area (NTS 64K13SE and 14SW), Manitoba
by H.P. Gilbert 45

GS-6 Rare Earth Element Geochemistry of Sulphide-bearing Strata in the Flin Flon–Snow Lake Area (NTS 63K), Manitoba
by G.H. Gale 59

GS-7 Rare Earth Geochemistry of the Sneath Lake Mineral Occurrence (NTS 63K16), Manitoba
by G.H. Gale 63

GS-8 Vectoring Volcanogenic Massive Sulphide Mineralization at the Raindrop Zone, Snow Lake (NTS 63K16), Manitoba
by G.H. Gale 69

GS-9 Geochemistry of Drillcore Samples, Alders, Peat, Bog Iron and Till at Reed Lake, Manitoba (NTS 63K9)
by G.H. Gale 75

GS-10 Geology of the New Britannia Mine, Snow Lake (NTS 63K16), Manitoba
by G.H. Gale 83

GS-11 Platinum Group Element Investigations in the Flin Flon Greenstone Belt: Regional Geology of the McBratney Lake PGE-Au Occurrence and Part of the Mikanagan Lake Sill (NTS 63K13), Manitoba
by P. Theyer and T. Heine 87

GS-12 Platinum Group Element Investigations in the Flin Flon Greenstone Belt: Petrography and Mineralogy of the McBratney Lake PGE-Au Occurrence (NTS 63K13), Manitoba
by G. Olivo, P. Theyer and N. Bursztyn 94

GS-13 Activities of Manitoba's Flin Flon Regional Office
by T.H. Heine 100

THOMPSON NICKEL BELT, SUPERIOR BOUNDARY ZONE, FOX RIVER BELT

GS-14 Tectonostratigraphy, Sm-Nd Isotope and U-Pb Age Data of the Thompson Nickel Belt and Kisseynew North and East Margins (NTS 63J, 63P, 63Q, 64A, 64B), Manitoba
by H.V Zwanzig and Ch.O. Böhm 102

GS-15 Thompson Nickel Belt Project: Progress Report (Parts of NTS 63J, 63O and 63P), Manitoba
by J.J. Macek, C.R. McGregor and C.G. Couëslan 115

GS-16 Interpretation of Thompson-type Geophysical Signatures (NTS 63B and 63F) and the Possible Cause of the Camperville Gravity Low (NTS 62N and 63C), West-central Manitoba
by I.T. Hosain and J.D. Bamburak 117

GS-17 Phanerozoic Solid-sulphide Occurrence Containing Devonian Dolomite Breccia Clasts, Pemmican Island, Lake Winnipegosis (NTS 63B12NW), Manitoba
by J.D. Bamburak, I.T. Hosain and K. Klyne 131

LYNN LAKE-LEAF RAPIDS

GS-18 Churchill River–Southern Indian Lake Targeted Geoscience Initiative (NTS 64B, 64C, 64G, 64H), Manitoba: Update and New Findings
by D. Corrigan and N. Rayner 144

GS-19 Structural Analysis and Geochronological Studies in the Lynn Lake Greenstone Belt and its Gold-bearing Shear Zones (NTS 64C10, 11, 12, 14, 15 and 16), Manitoba
by C.J. Beaumont-Smith and Ch.O. Böhm 159

GS-20 Structure and Stratigraphy in the Agassiz Metallotect, Lynn Lake Greenstone Belt (NTS 64C14 and 64C15), Manitoba
by A.F. Park, C.J. Beaumont-Smith and D.R. Lentz 171

GS-21 Discovery of a Carbonatite Complex at Eden Lake (NTS 64C9), Manitoba
by A.H. Mumin 187

GS-22 Geology and Geochemistry of the Ruttan and Darrol Lake Deposits (NTS 63B5), Manitoba
by G.H. Gale, S.H. McClenaghan and R. Yaworski 198

GS-23 Determining Residual Mineral Potential Using Europium Anomalies in the Ruttan and Lynn Lake Areas, Manitoba
by G.H. Gale and S.H. McClenaghan 205

NORTHERN SUPERIOR

GS-24 Quaternary Stratigraphy and Ice-flow History Along the Lower Nelson, Hayes, Gods and Pennycutaway Rivers and Implications for Diamond Exploration in Northeastern Manitoba
by E. Nielsen 209

GS-25 Tectonostratigraphic Panels and Early Deformation in the Island Lake Greenstone Belt (NTS 53E15 and 16), Northwestern Superior Province, Manitoba
by J. Parks, S. Lin, M.T. Corkery, K.Y. Tomlinson and D.W. Davis 216

GS-26 Deformation History of the Northwestern Cross Lake Greenstone Belt (NTS 63I12), Northwesternern Superior Province, Manitoba
by T. Dai, D. Jiang and M.T. Corkery 226

SOUTHEASTERN MANITOBA

GS-27 Preliminary Report on the Geology and Structure of the Garner Lake Area, Southeast Rice Lake Greenstone Belt (NTS 52L14), Manitoba
by S.D. Anderson 234

GS-28 Platinum Group Element Investigations in the Peterson Block of the Bird River Sill (NTS 52L5NE), Manitoba
by P. Theyer 250

GS-29 Phytoremediation of Mine Tailings and Bio-ore Production: Progress Report on Seed Germination, Survival and Metal Uptake of Seedlings Planted at Central Manitoba (Au) Minesite (NTS 52L13)
by S. Renault, E. Sailerova and M.A.F. Fedikow 255

SOUTH-CENTRAL MANITOBA

GS-30 Capital Region Study (Winnipeg and Surrounding Areas) Update and Stratigraphic Drilling 2002, Manitoba
by R.K. Bezys, J.D. Bamburak and G.G. Conley 266

GS-31 The Manitoba Stratigraphic Database and Capital Region Study: an Update
by G.G. Conley 273

GS-32 Development of Methods for 3-D Geological Mapping of Southern Manitoba Phanerozoic Terrane
by G.L.D. Matile, G.R. Keller, D.M. Pyne and L.H. Thorleifson 274

GS-33 Contributions of Dendrochronology to Flood Hazard Analysis in the Red River Basin, Manitoba
by S. St. George and E. Nielsen 283

GS-34 Kimberlite Indicator Minerals From West-central Manitoba — 2002 Update (NTS 63C and 63K)
by J.D. Bamburak and M.A.F. Fedikow 287

GS-35 Aggregate Resources in the Rural Municipalities of Ste. Anne and Turtle Mountain, and in the Buffalo Point Area, Manitoba
by H.D. Groom 295

MANITOBA GENERAL

GS-36 Scoping Study for Hydrothermal Iron-oxide Copper-gold Deposits (Olympic Dam–type), Manitoba
by A.H. Mumin 303

GS-37 Industrial Mineral Potential of Mafic-ultramafic Intrusions in Manitoba
by P.D. Leskiw 309

GS-38 Manitoba Mineral Inventory
by J.J. Johnson, L. Janower and J.D. Bamburak 310

GS-39 Manitoba's Precambrian Drill Core Libraries Program: An Update
by D.E. Prouse 312

PUBLICATIONS

Preliminary Maps 317

Publications Released November 2001 - November 2002 318

External Publications 323

ANNUAL REVIEW

by E.C. Syme, Director, Manitoba Geological Survey

Syme, E.C. 2002: Annual review; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 1–8.

INTRODUCTION

The primary role of the Manitoba Geological Survey (MGS) is to provide geoscience information to support and facilitate mineral exploration in the province. Increasingly, however, MGS is conducting a broader range of geoscience activities that address a number of key issues facing Manitobans. Examples in this *Report of Activities* include assessment of past flood events in the Red River valley, construction of three-dimensional models of surficial materials and bedrock in southern Manitoba (with implications for groundwater studies), and the Capital Region Study (providing industrial mineral, aggregate and engineering information for municipalities in the most heavily populated part of the province).

The 2002–2003 geoscience program thus reflects a balance between providing support to traditional mining camps, stimulating new exploration and development opportunities in frontier areas, and supporting land-use, geohazard and development priorities in southern Manitoba. The program is reviewed annually by the Mineral Exploration Liaison Committee (MELC), composed of members of the Mining Association of Manitoba, the Manitoba Prospectors and Developers Association and the Manitoba-Saskatchewan Prospectors and Developers Association, as well as representatives from the University of Manitoba and the Geological Survey of Canada (GSC).

GEOSCIENCE PROGRAM

The MGS geoscience program is designed with a regional emphasis, focusing on those areas most in need of new or updated geological information. In 2002–2003, approximately 20% of the total project-related operating budget was directed toward studies in the northern Superior Province, primarily for programs in support of diamond-related exploration. Approximately 53% of the project-related operating budget was directed toward projects within traditional mining camps: Flin Flon Belt, Lynn Lake Belt, Thompson Nickel Belt and southeastern Manitoba. The remaining 27% supported Quaternary, aggregate, industrial minerals and land-use planning in the south-central part of the province, as well as province-wide projects.

In 2002, the MGS had planned to embark on a multiyear surficial geochemistry and kimberlite indicator-mineral (KIM) survey in the Kasmere-Nueltin lakes area. Budget reductions in the spring forced a deferral of this project and a redirection of effort toward completion of the Quaternary stratigraphy study in the Hudson Bay Lowland.

PARTNERSHIPS AND COLLABORATIVE PROJECTS

Partnerships or collaborative projects with external agencies and organizations form an increasing proportion of the MGS geoscience program. Such partnerships make best use of combined funds and expertise, and result in high-quality, focused, effective programs. The partnered initiatives include contributions from the federal government, the mineral-exploration industry and several Canadian universities (Table 1). These partnerships are expected to add approximately $1.3 million to geoscience programming in Manitoba for 2002–2003, representing significant leverage of the MGS geoscience budget.

The largest partnership is with the Geological Survey of Canada (GSC) and related sections of Natural Resources Canada, which contribute 55% of the total partnership funding. Under the Government of Canada's $15 million, three-year Targeted Geoscience Initiative (TGI), the GSC is involved in two projects located in Manitoba and adjoining portions of Saskatchewan. Funding from GSC through the TGI is matched by funding and in-kind contributions by MGS and the Saskatchewan Geological Survey (SGS). The mapping projects will significantly increase understanding of the geology and mineral deposits in Lynn Lake–Leaf Rapids and Flin Flon regions, where there is significant potential for the discovery of new base- and precious-metal deposits.

The mineral-exploration industry supports a broad range of partnerships ranging from geochronological studies along the Superior Boundary Zone to mineralogical studies in the Flin Flon area. They are also closely tied to both of the TGI programs with the GSC. Manitoba Hydro is sponsoring a major three-year program in the Gull Rapids region in concert with the universities of Alberta, Manitoba and Waterloo.

Table 1: Partnership geoscience projects, 2002–2003.

PROJECT AND PARTNERS	CURRENT STATUS (2002)
Flin Flon–Snow Lake	
Flin Flon TGI (GSC, SGS, HBED, Aur Resources Inc., Laurentian U)	Third year of a three-year project; fieldwork at Flin Flon and Baker Patton; three M.Sc. and two B.Sc. theses in progress; see GS-1, -2, -3 and -4; maps to be released as open files in late 2002 and digital release planned for 2003; seven papers planned for GAC-MAC 2003
Snow Lake gold studies (TVX Gold Inc., U of Manitoba)	Sixth year of ongoing project; two M.Sc. theses completed; see GS-10
Snow Lake base-metal vectors (Callinan Mines Ltd., W. Bruce Dunlop Ltd.)	Third year of ongoing project; data collection dependent upon availability of drill core; see GS-7, -8 and -9
PGE in the Flin Flon Belt (Fort Knox Gold Resources Inc.)	Geological mapping, sampling; geochemical investigations ongoing; see GS-12
Lynn Lake–Leaf Rapids	
Lynn Lake gold studies (U of New Brunswick, Laurentian U, U of Manitoba, NSERC)	Third year of a three-year project; part of Manitoba's contribution to the Lynn Lake–Leaf Rapids TGI; one Ph.D. and two M.Sc. theses in progress; see GS-20 and -19
Lynn Lake isotopic studies (U of Alberta)	Part of Manitoba's contribution to the Lynn Lake–Leaf Rapids TGI; see GS-19
Lynn Lake–Leaf Rapids TGI (GSC, HBED, Aur Resources Inc.)	Second year of a two-year project; fieldwork in the Granville Lake and Southern Indian Lake areas; see GS-18 and Preliminary Map 2002-3
Ruttan REE geochemistry study (HBMS)	First year of a three-year project to study REE profiles as a vector to VMS mineralization; see GS-22
Thompson Nickel Belt	
Thompson Nickel Belt CAMIRO 97E-02 (Inco Ltd., Falconbridge Ltd., HBED, Billiton Metals Canada Inc., Western Mining International Ltd., Laurentian U, U of Manitoba, U du Québec à Montréal, U of Alberta, U of Sask., GSC, NSERC)	Completed; final report being edited at Laurentian University
Gull Rapids Project (Manitoba Hydro, NSERC, U of Manitoba, U of Alberta, U of Waterloo)	New project in the Superior Boundary Zone; two field trips and sampling commenced in the Gull Rapids area; proposals will be forwarded to NSERC in fall of 2002
Fox River belt geology and metallogeny (Falconbridge Ltd., U of Manitoba)	Ph.D. at U. of Manitoba in progress
Isotopic studies, TNB extension (HBED, Inco)	New isotopic studies northeast of Thompson in the TNB northern extension; see GS-14
Northern Superior	
Western Superior NATMAP (OGS, GSC, universities, LITHOPROBE, NSERC)	Final year of project (1996–2002); 1:250 000-scale maps and papers in progress
Operation Superior multimedia and kimberlite indicator-mineral surveys (De Beers Canada Exploration Corp.)	Project complete; 2001 KIM data (OF2002-1) and 2000 geochemistry data (OF 2001-1) released in June 2002
Hudson Bay Lowlands project (De Beers Canada Exploration Corp.)	New project to map and sample tills, this year along the Nelson, Hayes, Gods and Pennycutaway rivers; see GS-24

Table 1: Partnership geoscience projects, 2002–2003. (continued)

PROJECT AND PARTNERS	CURRENT STATUS (2002)
Cross Lake structural studies (U of Maryland, U of Waterloo)	Final year of an M.Sc. on Pipestone Lake area (base map of Pipestone Lake to be released in 2003); second year of a Ph.D. in central Cross Lake; see GS-26
Island Lake supracrustal studies (U of Waterloo)	Third year of a structure-geochronology Ph.D. thesis; see GS-25 and Preliminary Map 2002-2
Southeastern Manitoba	
Western Superior NATMAP (OGS, GSC, universities, LITHOPROBE, NSERC)	Final year of project (1996–2002); 1:250 00-scale maps and journal papers in progress
Isotopic studies in the southeastern Rice Lake belt (U of Alberta)	Sampling for geochronology carried out in the Garner-Gem lakes area, summer 2002; lab work in progress; see GS-27
Precambrian monadnocks apatite fission-track dating (GSC-C; U of Melbourne)	Ongoing Ph.D.
Southern Manitoba	
Hydrogeology (GSC, WRB, U of Manitoba)	Final year of project (1996–2002); four M.Sc., one Ph.D. and two post-doc
Greater Winnipeg NATMAP (GSC, universities)	Final year of project (1997–2002); two M.Sc., two Ph.D. and two post-doc; reports and papers in progress
Paleofloods of the Red River (GSC, IJC, RRFPP)	Program in last year; three journal papers published in 2002 and data posted on the NOAA web site; see GS-33
Prairie-type mineralization (U of Manitoba, U du Québec à Montreal, U of Alberta, U of Brussels, GSC-C)	Ongoing B.Sc. at U of Manitoba
Devonian mapping (U of Manitoba)	New proposal; will result in preliminary reports and maps from M.Sc. student
Reprocessing of LITHOPROBE The Pas moraine line (GSC)	New proposal
Airphoto interpretation of east side of Lake Winnipeg	New proposal for airphoto interpretation of a corridor east of Lake Winnipeg to outline options for laying a cable between Gillam and southern Manitoba (2002–2003)
Aggregate inventory (T&GS)	Ongoing; MGS provides field data to T&GS and T&GS processes aggregate samples; see GS-35
Hydrothermal iron-oxide copper-gold deposit (Olympic Dam–type) scoping study (Brandon University)	New project to study the potential for Olympic Dam–type deposits in Manitoba; see GS-36
3-D geological model of southern Manitoba (GSC)	Ongoing; providing a digital elevation model for southern Manitoba and models of Phanerozoic stratigraphy; see GS-32 and two pages on MGS website

Abbreviations: CAMIRO, Canadian Mining Industry Research Organization; **GAC**, Geological Association of Canada; **GSC**, Geological Survey of Canada (GSC-C, GSC Calgary); **HBED**, Hudson Bay Exploration and Development Co. Ltd.; **HBMS**, Hudson Bay Mining and Smelting Co. Ltd.; **IJC**, International Joint Commission; **LITHOPROBE**, Canada's National Geoscience Program; **MAC**, Mineralogical Association of Canada; **NATMAP**, National Geoscience Mapping Program; **NSERC**, Natural Sciences and Engineering Research Council; **OGS**, Ontario Geological Survey; **PGE**, platinum group elements; **RRFPP**, Red River Flood Protection Program; **SGS**, Saskatchewan Geological Survey; **T&GS**, Manitoba Department of Transportation and Government Services; **TGI**, Targeted Geoscience Initiative; **U**, University; **VMS**, volcanogenic massive sulphide; **WRB**, Water Resources Branch

FLIN FLON–SNOW LAKE

The Flin Flon Belt hosts some of the province's most significant volcanogenic massive sulphide deposits; greenstone belts within the Trans-Hudson Orogen are in fact among the most productive belts in the world. Despite the fact that Flin Flon has superb outcrop exposure of greenschist-grade metavolcanic rocks, the stratigraphic setting of the Flin Flon, Callinan and 777 deposits (totalling almost 100 million tonnes) is poorly known because the host rocks straddle the boundary between Manitoba and Saskatchewan. To address this jurisdictional anomaly and better define the setting of these deposits, the recent Flin Flon TGI called on the combined expertise of MGS, SGS, GSC and university researchers.

The Flin Flon TGI project wrapped up its last field season in 2002, with researchers from Laurentian University conducting 1:500-scale mapping, predominantly in the stratigraphic footwall of the 777 and Callinan deposits, and finalizing thesis project work (GS-1 to -4). Staff from the Saskatchewan and Manitoba geological surveys collaborated on constructing a 1:10 000 cross-border compilation of the Flin Flon area that will place the more detailed studies in their regional context. Staff from the GSC conducted alteration studies in the Bear Lake Block and hanging wall of the Flin Flon–Callinan–777 deposits. These projects have produced important new insights into the setting of volcanogenic massive sulphide deposits in the west-central Flin Flon Belt.

Regional mapping focused on the central and north parts of Alberts Lake and the contiguous area between Alberts Lake and Lac Aimée, completing work that had been conducted in 1996, 1997 and 2002. This regional mapping was undertaken to upgrade outdated (1940s vintage) geological maps in the north part of the Flin Flon Belt, in order to assess the tectonostratigraphic and economic significance of the volcanic rock assemblages (GS-5).

Thematic mineral deposit studies were conducted in Snow Lake on base-metal projects (GS-6 to -8), on the New Britannia gold mine (GS-10), and in the Reed Lake area on volcanogenic massive sulphide deposits (GS-9).

Platinum group element (PGE) studies in the Flin Flon Belt focused on mafic and ultramafic intrusive rocks within the Bear Lake Block, host to the McBratney Lake occurrence (GS-11). The McBratney occurrence is an example of hydrothermal PGE-Au mineralization, hosted by the mafic volcanic rocks and characterized by extensive carbonate-chlorite-sulphide alteration (GS-12).

THOMPSON NICKEL BELT–SUPERIOR BOUNDARY ZONE

The Superior Boundary Zone, including the well-known Thompson Nickel Belt (TNB), is host to world-class nickel deposits and holds much promise in future exploration for base metals, platinum group metals, gold and diamonds. Current work in the TNB and surrounding region builds on outcomes from two major collaborative projects that have been recently completed:

1) The TNB CAMIRO project (1997–2001) had five industry sponsors (Inco Ltd., Falconbridge Ltd., Hudson Bay Exploration and Development Co. Ltd., Billiton Metals Canada Inc. and Western Mining International Ltd.) and included researchers from the GSC, MGS, University of Manitoba, Laurentian University, University of Alberta, Université du Québec à Montréal, and University of Saskatchewan.

2) The TNB compilation project (1995–present) is a collaborative program designed to create new compilation maps for the TNB. Maps are produced by MGS in joint authorship with geological staff of Inco Ltd., Falconbridge Ltd. and Hudson Bay Exploration and Development Co. Ltd. A preliminary version of the TNB compilation was released in June 2001, coinciding with the completion of the TNB CAMIRO project.

Work to clarify the structure, mineral potential and extent of the TNB in north-central Manitoba involved the application of combined remapping, core relogging and isotopic dating techniques (GS-14). Application of Sm-Nd isotope methods and U-Pb dating to these Precambrian medium- to high-grade gneiss units provides a clear distinction between 1) Neoarchean basement, 2) Paleoproterozoic Ospwagan Group cover rocks (hosting nickel deposits), 3) juvenile Paleoproterozoic paragneiss, and 4) a Mesoarchean gneiss complex (the likely host of important precious-metal prospects). This work is being conducted collaboratively with the University of Alberta, Inco Technical Services Ltd., Nuinsco Resources Ltd., Hudson Bay Exploration and Development Co. Ltd., and ProRock Exploration Inc.

In the TNB compilation project, a new topographic map was largely completed for the exposed part of the TNB, utilizing new orthophoto tiles (GS-15). Upon completion, the map will serve as a base for the final geological compilation map. During the summer of 2002, the four-year program of re-examining Bucko diamond-drill core was completed. All retrieved geological information will be incorporated into the final TNB compilation map.

LYNN LAKE–LEAF RAPIDS

Recent mine closures at Lynn Lake and Leaf Rapids have highlighted the need for new geoscience studies in the region, to encourage new exploration and development. At Lynn Lake, regional gold metallogenic studies were begun in 2000. The closure, in June 2002, of the Ruttan mine in Leaf Rapids precipitated a number of studies aimed at collecting as much information about the deposit as possible while the mine infrastructure was still in operation.

During the months of February and March 2002, MGS geologists and a GSC contractor undertook detailed mapping and sample collection underground at Ruttan, to document the geology of the deposit and to collect samples that will be analyzed for their chemical contents and characteristic mineral assemblages. The results of these studies will assist in the development of a geoscientific database that will support mineral exploration in the Rusty Lake greenstone belt.

Drill cores from regional exploration programs in the Ruttan and Lynn Lake areas were examined in 2002 for evidence of stratiform sulphide mineralization (GS-23). Cores containing cherts, barren sulphides and sulphidic sedimentary rocks were sampled, and will be analyzed to determine which ones could be spatially associated with base-metal VMS-type mineralization. Drill cores were also logged in detail to establish the stratigraphic position and setting of 'ore equivalent' strata at the Ruttan and Darrol Lake deposits (GS-22).

The Lynn Lake–Leaf Rapids TGI project entered its second and final year of field studies. The GSC component of the project is directed at upgrading the understanding of the lithological and tectonic framework the Trans-Hudson Orogen's northern flank, with a main objective of providing a regional geological context to mineral deposits (GS-18). The first field season (in 2001) was concentrated on the northern half of the transect, from the central part of the Rusty Lake belt to the Chipewyan Batholith. During the 2002 field season, the transect was completed from the central Rusty Lake belt southwards to the northern flank of the Burntwood Group in the Kisseynew Domain.

The MGS component of the Lynn Lake–Leaf Rapids TGI is aimed at an evaluation the precious- and base-metal mineral potential of the area, in order to facilitate exploration activity. The MGS started a five-year multidisciplinary initiative at Lynn Lake in June 2000, and rolled this project into the TGI in 2001. The range of projects includes deposit-scale studies, structural mapping of mineralized shear zones, and geochronological studies that will provide a temporal context for the development of the greenstone belt and its mineral deposits (GS-19 and -20). These projects have resulted in a much better understanding of the 'Agassiz Metallotect' (host of the past-producing MacLellan mine), the Johnson Shear Zone (host of the past-producing BT gold deposit), and the evolution and deformation of the Lynn Lake greenstone belt.

A preliminary scoping study was undertaken to assess the potential of Manitoba to host hydrothermal iron-oxide copper-gold (IOCG- or Olympic Dam–type) deposits (GS-36). At the outset of this project, there were no known examples of IOCG-type deposits in the province, nor has there been any recorded exploration for these deposits. Preliminary fieldwork was carried out in 2002, including a regional overview and reconnaissance visits to several of the priority targets. Reconnaissance fieldwork confirms the presence of widespread alkali±iron and other related metasomatic effects associated with late intrusive bodies and large structural lineaments. However, the most important finding to date resulting from this initiative is the discovery of a large carbonatite complex, enriched in rare earth elements, near Eden Lake (GS-21).

NORTHERN SUPERIOR PROVINCE

With the Western Superior NATMAP project in its last year of operation, related activities in 2002 concentrated on data compilation and synthesis. A cross-border compilation of the Uchi Belt in southeastern Manitoba and northwestern Ontario has been completed and will be released early in 2003. A similar compilation of greenstone belts in the Sachigo Domain is in progress. These maps integrate new data collected during the NATMAP project and will form the base maps for geochronological and mineral-deposit data served over the Internet.

Field projects partnered with Waterloo University and the University of Maryland provided critical new information for the Island Lake (GS-25) and Cross Lake (GS-26) greenstone belts, respectively. Field mapping and geochemical and geochronological work demonstrate that the Hayes River Group on Island Lake consists of lithologically, geochemically and chronologically distinct panels, and that at least three distinct volcanic episodes are recorded in this greenstone belt.

Field investigations into the Quaternary stratigraphy, ice-flow history, till provenance and kimberlite indicator-mineral (KIM) distribution in the Hudson Bay Lowland continued in 2002, in support of diamond exploration (GS-24). Published results from the 2001 survey suggest that KIM were concentrated in Long Spruce till of northern provenance. During the 2002 field season, 144 till and 3 alluvial sand and gravel samples were collected from 17 sections exposed in river cuts in the Hudson Bay Lowland.

SOUTHEASTERN MANITOBA

The Rice Lake greenstone belt, located in the western portion of the Archean Uchi Subprovince, is the most significant lode-gold district in Manitoba, with more than 1.6 million ounces of past gold production. In 2002, the MGS initiated a multidisciplinary program of targeted 1:20 000-scale bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology in the Rice Lake belt (GS-27). The objective of this program is to further refine the stratigraphic, structural and tectonic framework of the belt, with particular emphasis on gold metallogeny. Fieldwork in 2002 focused on detailed mapping and sampling of a roughly 12 km transect across the southeastern portion of the Rice Lake belt, utilizing exposures along the Gem Lake logging road and the shoreline of Garner Lake.

The Bird River Sill, a repository of significant chromite resources, supported two nickel-copper mines and, in the past decade, has been explored for PGE (GS-28). In the southern part of the sill, exploration concentrated on the Chrome property and, to a lesser degree, on the Page property. Significant PGE concentrations discovered in 2001 brought the 'Peterson Block', located between the Chrome and Page properties, to the attention of explorationists. A number of rock samples were collected from mineralized zones in the Peterson Block and will be analyzed for PGE.

A project was initiated in 2000 at the Central Manitoba (Au) mine site in southeastern Manitoba to determine the potential for revegetation, phytoremediation and phytomining of mine tailings through the identification of plant species that can avoid or tolerate the presence of heavy metals (GS-29). The focus of fieldwork and the greenhouse experiments in the coming growing season will be to determine the best combination of different amendments to the tailings surface layer, in order to increase the long-term survival rate of selected plant species.

SOUTH-CENTRAL MANITOBA

Activities of the MGS in south-central Manitoba ranged from an investigation of sulphide mineralization in Phanerozoic bedrock in the Interlake district, to dendrochronology in the Red River valley.

Gravity and magnetic surveys were carried out in the summers of 2000 and 2001 over the southern extension of the Superior Boundary Zone (GS-16). The surveys were carried out to delineate the Thompson Nickel Belt below the Paleozoic cover rocks and to determine the cause of a neighbouring gravity low in the Camperville area. In the latter area, a large (approximately 120 by 60 km), ellipsoidal, 35 mGal gravity low is interpreted to be a granitic intrusion with high magnetite content.

Large solid sulphide slabs, containing breccia clasts of sucrosic Devonian dolomite, were found just below the waterline on Pemmican Island at the north end of Lake Winnipegosis (GS-17). These slabs contain up to 1.18% Ni and 0.76% Zn and, together with other anomalous features in the Phanerozoic, point to the possible role of basement reactivation in the buried Thompson Nickel Belt.

Follow-up investigations of kimberlite indicator minerals (KIM) in the Porcupine Hills of west-central Manitoba confirmed that the northern half of the region contains anomalous quantities of KIM compared to the southern half (GS-34). The KIM are not derived from the Cretaceous Swan River Formation, but may have been eroded from younger Cretaceous beds or from the multiple till sheets that are draped over the Porcupine Hills.

In the Capital Region Study, several municipalities in the Winnipeg region have been mapped and assessed for aggregate and crushed stone, to aid local land-use planning processes (GS-30). Through compilation of quarry, outcrop, water-well and corehole data, new 1:50 000-scale depth to bedrock, bedrock topography, geology and mineral potential maps are being released in final format, accompanying a geological report for NTS map sheets 62H10, 11, 14 and 15, and 62I2, 3, 6 and 7. As a result of this work, six new areas with potential for crushed stone have been identified in and around the Capital Region.

Three-dimensional geological mapping of the Phanerozoic succession in southern Manitoba, south of latitude 55°N and west of longitude 95°W, is being completed as a successor activity to the Prairie NATMAP project (GS-32). The mapping utilizes computer technology and is designed to support activities related to hydrocarbon, groundwater and industrial-mineral development. Much of the input data is in place (topography, bathymetry, offshore geology, soil mapping, surficial geology, Quaternary stratigraphy, bedrock surface, bedrock geology, Phanerozoic stratigraphy, sub-Phanerozoic Precambrian geology, drillhole data). The drillhole data compilation now links to water-well data held by the Water Branch of Manitoba Conservation, the Manitoba Stratigraphic Database, Manitoba Oil and Gas Well Information System, and newly digitized records held by MGS. The key activities during 2001–2002 have been selection of computer hardware and software, and refinement of model construction, verification, and communication procedures.

Research conducted by the joint MGS-GSC dendrochronological laboratory in Winnipeg has provided baseline geoscientific data critical to the understanding of past hydroclimatic change in Manitoba and its impact on flood hazards in the Red River valley and local groundwater supplies (GS-33). The current tree-ring record for the Red River basin extends back to AD 1286 and has been used to construct a flood history for the Red River at Winnipeg that spans the last 350 years.

AGGREGATE

Aggregate inventories were carried out in the Rural Municipalities of Ste. Anne and Turtle Mountain, in the Buffalo Point area, and on several crown-land parcels in southeastern Manitoba (GS-35). Site inspection and aggregate sampling followed office compilation. Samples were field sieved and a representative portion of the fine fraction sent to Winnipeg for processing. Approximately 350 sites were visited.

LAND USE

The Manitoba Geological Survey conducts a number of activities related to sound land-use management: 1) provision of mineral-resource assessments in candidate sites under the Protected Areas Initiative; 2) identification of potential geological hazards (shoreline erosion, neotectonics, landslides); 3) review of land-use planning submissions; 4) examination of applications for surface use of crown land to ensure that access to mineral occurrences is not adversely affected; and 5) collaborative programs with Manitoba Conservation, Manitoba Hydro and the GSC to evaluate geological hazards and potential impacts on development.

The Prospectors and Developers Association of Canada introduced its 'Claim Tag Awards', which were presented during the annual Energy and Mines Ministers Conference in Winnipeg in September. Manitoba received a second place award "in recognition of the Manitoba government's ongoing facilitation of a technically advanced, methodical and transparent process of multistakeholder involvement in creating protected areas."

PRECAMBRIAN DRILL CORE LIBRARIES

Manitoba's Mineral Resources Division has been storing Precambrian drill core, obtained primarily from exploration drilling, since the early 1970s (GS-39). Since that time, the Manitoba government has created a substantial repository of drill core at five locations throughout the province. Throughout most of the 1990s, the core libraries were run on a care-and-maintenance basis. In 2001, recent drill-core additions were organized and core-library inventories were updated. Working in conjunction with Hudson Bay Exploration and Development Co. Ltd. (HBED) and Ruttan mine geological staff, a summer field program was conducted to retrieve and store Ruttan regional exploration drillholes in the MGS Lynn Lake Core Library.

GEOSCIENCE INFORMATION SERVICES

The Geoscience Information Services section is responsible for all data management, GIS, and CAD production and geological compilation in the MGS. Many of the projects underway are focused on bringing data to the Internet. The MGS policy is that, whenever possible, newly published reports and maps will be placed on the Industry, Trade and Mines website in electronic form for free download. This free download feature, combined with extensive use of the Internet Map Server ('GIS Map Gallery') has enabled the MGS to substantially increase the amount of information on geoscience in Manitoba that is available quickly through the Internet.

The Manitoba Mineral Inventory (MMI) is an indexed group of hard-copy cards and computer files, maintained by the MGS, that contains the majority of known mineral deposits in Manitoba. The MGS is working on the MMI, with the goal of updating the entire inventory and increasing accessibility by bringing it onto the Internet (GS-38).

Two new A-series printed maps (NTS 64O and 63G) were released this year in the 1:250 000 Bedrock Geology Compilation Map Series (BGCMS). The BGCMS maps are being added to the Internet Map Gallery as individual NTS map sheets, providing a more detailed and current geological base for viewing other data sets such as claim and lease maps. Currently, there are 29 BGCMS maps in digital form and 21 will be available shortly in the GIS Map Gallery. These maps, which are currently being edge-matched, will eventually be used in the Map Gallery as a seamless 1:250 000-scale geological base.

Several new features have been added to the Internet Map Server. The look of the GIS Map Gallery has been changed to improve the usability of the site and the live printing of maps. New map services added, in addition to the BGCMS, include the 1:100 000-scale NATMAP Shield Margin Project map of the Flin Flon Belt in Manitoba and Saskatchewan and the 1:250 000-scale 'Geoscience data compilation for southeastern Manitoba' (Open File Report OF2001-8). In addition to new maps, all GIS Map Gallery geoscientific maps now include layers of point data for geochronology and mineral occurrence descriptions. These points are 'hotlinked' to descriptive documents and graphics that can be accessed by selecting the point with the hotlink tool in the Map Gallery. Both databases are continually being expanded and new records will be added to the website as they become available.

CLIENT SERVICES

Client Services provides communications, outreach and information production and dissemination services for the Mineral Resources Division, to assist in the promotion of exploration and mining investment opportunities and increase public awareness of the benefits and opportunities of sustainable mineral development. Responsibilities include the web publishing of minerals-related content for the departmental web site and the production and distribution of MGS publications and promotional materials. These publications, as well as other minerals-related information resources, are disseminated through library services, publication sales and the Mineral Resources Division web site. Library and publication sales staff worked on major initiatives that will provide web access to the library catalogue, the *Bibliography of Manitoba Geology* and mineral-inventory records, as well as on-line purchasing of MGS reports and maps.

REGIONAL OFFICES

The Flin Flon regional office continues to provide assistance to the mineral-exploration and mining communities in the Flin Flon–Snow Lake region, including recording new mineral claims, maintaining an up-to-date library of provincial claim and land-status maps, dealing with claim-status inquiries and accepting assessment-work submissions. In October–November 2002, a Mining Claims Inspector and a Mining Recorder will augment the staff of two geologists currently in the Flin Flon office. An inventory is in preparation of the core repository at the Centennial mine site and all core piles have been reorganized and stabilized. The mine-documentation project is proceeding with the addition of new ore samples from a number of now-closed mines and the establishment of a database for the core repository at the Stall Lake mine near Snow Lake.

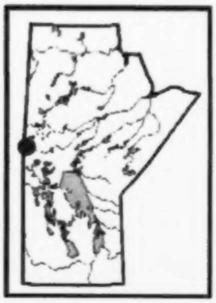
Staff in the Thompson regional office respond to a range of inquiries, including regional geology, potential of mineral properties and mineral identifications. The Thompson office provides Mining Recording services to the community, including data on the status and registration of claims, access to and sales of maps and reports, and access to electronic databases.

ACKNOWLEDGMENTS

The meticulous work of the entire MGS — field geologists, lab technicians, expeditors, students, cartographers, publication staff and administration — went into the production of the Report of Activities 2002. Bob Davie and Joan Dawson of RnD Technical carefully performed technical editing. The hard work of all these people is gratefully acknowledged.

GS-1 STRATIGRAPHY OF VOLCANOGENIC MASSIVE SULPHIDE-HOSTING VOLCANIC AND VOLCANICLASTIC ROCKS OF THE FLIN FLON FORMATION, FLIN FLON (NTS 63K12 AND 13), MANITOBA AND SASKATCHEWAN

by C.A. Devine[1], H.L. Gibson[1], A.H. Bailes, K. MacLachlan[2], K. Gilmore[3] and A.G. Galley[4]



Devine, C.A., Gibson, H.L., Bailes, A.H., MacLachlan, K., Gilmore, K. and Galley, A.G. 2002: Stratigraphy of volcanogenic massive sulphide-hosting volcanic and volcaniclastic rocks of the Flin Flon formation, Flin Flon (NTS 63K12 and 13), Manitoba and Saskatchewan; *in* Report of Activities 2002, Manitoba Industry Trade and Mines, Manitoba Geological Survey, p. 9-19.

SUMMARY

Detailed stratigraphic sections, 1:500-scale mapping, clast counts and descriptions of the footwall stratigraphy to the Flin Flon, 777 and Callinan volcanogenic massive sulphide (VMS) deposits have established several distinctive eruptive and volcaniclastic members belonging to a newly defined unit, the Flin Flon formation. Detailed stratigraphic correlation of the newly defined members has assisted identification of stratigraphic repetitions due to early thrust faulting and associated drag folding. This better understanding of the stratigraphy, depositional environment and subsequent deformation will allow a more comprehensive analysis of the present position of the VMS horizon in three dimensions.

INTRODUCTION

A complex succession of felsic and basalt-dominated heterolithic volcaniclastic rocks host the Flin Flon Main, Callinan and 777 volcanogenic massive sulphide (VMS) deposits within the Paleoproterozoic Flin Flon Belt of Manitoba and Saskatchewan (Fig. GS-1-1, GS-1-2). The north-trending, VMS-hosting, 30 to 700 m thick volcanic-volcaniclastic succession is recognized for at least 5 km along strike and has an average dip of 60°E (Fig. GS-1-2). The volcaniclastic rocks have been interpreted to occupy a volcano-tectonic depression within a basaltic footwall succession (Syme and Bailes, 1993).

This study is part of the Flin Flon Targeted Geoscience Initiative, involving the Geological Survey of Canada, the Manitoba Geological Survey, the Saskatchewan Geological Survey and Laurentian University. Its goals are to refine our knowledge of the volcanic stratigraphy hosting the Flin Flon VMS deposits, establish the provenance of the clasts in volcaniclastic units, determine mechanisms by which the volcaniclastic breccias were emplaced, and ascertain their environment of deposition. This will assist in further exploration along the known VMS horizon through deep drilling, and establish the continuation and potential of this VMS-rich stratigraphic interval further to the south and west.

METHODOLOGY

To acquire the most quantitative data possible on the components, thickness and characteristics of the VMS host and footwall strata, fifteen detailed stratigraphic sections from surface and drillhole exposures, and eight 1:500-scale surface and underground maps were completed over a 5000 m long segment of the Flin Flon stratigraphy. This segment defines the footwall and host stratigraphy for over 80 million tonnes of massive sulphide mineralization in three known VMS deposits (Fig. GS-1-2).

More than 100 clast count locations were established using a 1 m by 1 m grid (121 points) to count clast populations and determine the amount of matrix. The long and short axes of the three largest clasts of each different clast type were measured within the grid boundaries, and detailed clast descriptions (colour, shape, phenocryst and amygdule size and percentage, and alteration mineralogy) were made. In addition, detailed depositional unit descriptions were collected, including amount and composition of matrix, sorting, thickness, bed forms and internal size grading. Observations with respect to the paragenetic sequence of syn- to postvolcanic dike emplacement were completed in order to determine focal points for dike activity during the evolution of the Flin Flon stratigraphy and generation of the VMS deposits. In conjunction with the trace- and major-element geochemistry, these data will be used to describe and reconstruct the volcano-tectonic depression that hosts the Flin Flon VMS deposits.

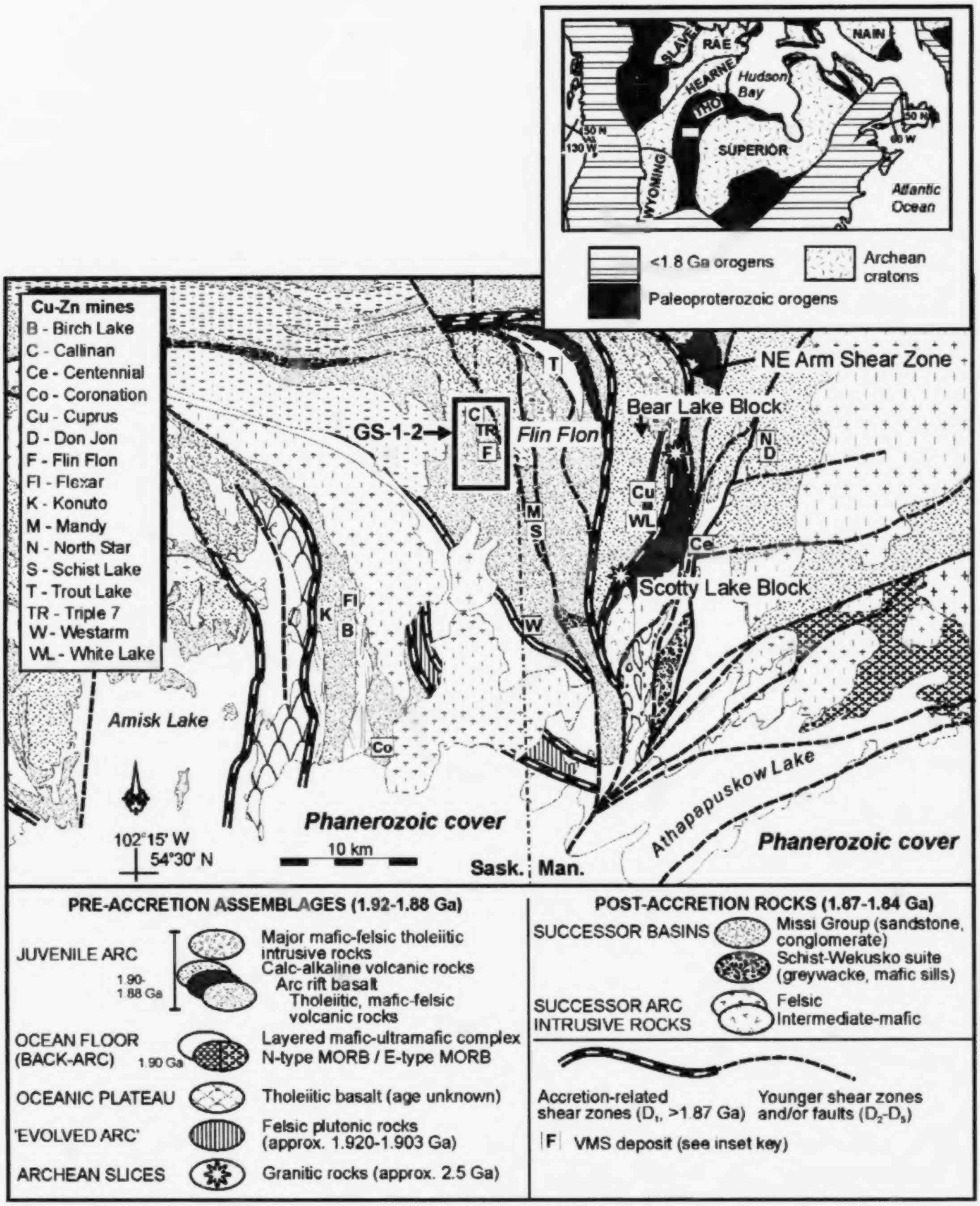
---

[1] Mineral Exploration Research Centre, Department of Earth Sciences, Laurentian University, Sudbury, Ontario P3E 2C6

[2] Saskatchewan Geological Survey, Saskatchewan Industry and Resources, 2101 Scarth Street, Regina, Saskatchewan S4P 3V7

[3] Hudson Bay Exploration and Development Ltd., P.O. Box 1500, Flin Flon, Manitoba R8A 0A2

[4] Geological Survey of Canada, 537-601 Booth Street, Ottawa, Ontario K1A 0E8



Cu-Zn mines
B - Birch Lake
C - Callinan
Ce - Centennial
Co - Coronation
Cu - Cuprus
D - Don Jon
F - Flin Flon
Fl - Flexar
K - Konuto
M - Mandy
N - North Star
S - Schist Lake
T - Trout Lake
TR - Triple 7
W - Westarm
WL - White Lake
SLAVE
RAE
HEARNE
NAIN
Hudson Bay
THO
SUPERIOR
WYOMING
50 N
130 W
50 N
60 W
Atlantic Ocean
<1.8 Ga orogens
Archean cratons
Paleoproterozoic orogens
NE Arm Shear Zone
Bear Lake Block
GS-1-2
Flin Flon
Scotty Lake Block
Amisk Lake
Phanerozoic cover
Athapapuskow Lake
Phanerozoic cover
102°15' W
54°30' N
10 km
Sask.
Man.
PRE-ACCRETION ASSEMBLAGES (1.92-1.88 Ga)
JUVENILE ARC
1.90-1.88 Ga
Major mafic-felsic tholeiitic intrusive rocks
Calc-alkaline volcanic rocks
Arc rift basalt
Tholeiitic, mafic-felsic volcanic rocks
OCEAN FLOOR (BACK-ARC)
1.90 Ga
Layered mafic-ultramafic complex
N-type MORB / E-type MORB
OCEANIC PLATEAU
Tholeiitic basalt (age unknown)
'EVOLVED ARC'
Felsic plutonic rocks (approx. 1.920-1.903 Ga)
ARCHEAN SLICES
Granitic rocks (approx. 2.5 Ga)
POST-ACCRETION ROCKS (1.87-1.84 Ga)
SUCCESSOR BASINS
Missi Group (sandstone, conglomerate)
Schist-Wekusko suite (greywacke, mafic sills)
SUCCESSOR ARC INTRUSIVE ROCKS
Felsic
Intermediate-mafic
Accretion-related shear zones (D1, >1.87 Ga)
Younger shear zones and/or faults (D2-D5)
F VMS deposit (see inset key)

Figure GS-1-1: Tectonic assemblages of the Flin Flon Belt, with locations of contained VMS deposits (modified from Syme et al., 1996).

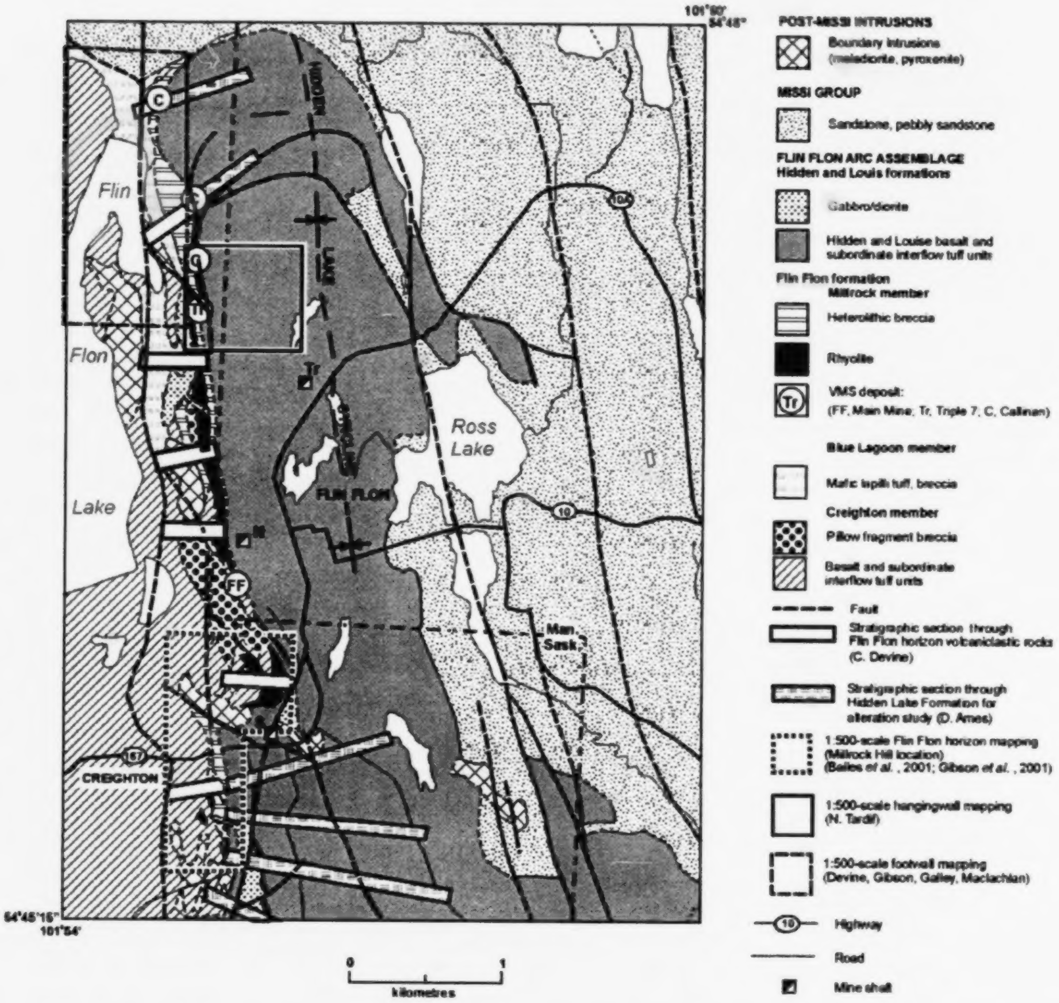

101°50'
54°48'
Flin
Flon
Lake
Ross
Lake
HIDDEN
LAKE
SYNCLINE
FLIN FLON
CREIGHTON
Man.
Sask.
C
F
G
E
FF
Tr
104
10
167
54°45'15"
101°54'
0
1
kilometres
POST-MISSI INTRUSIONS
Boundary intrusions (meladiorite, pyroxenite)
MISSI GROUP
Sandstone, pebbly sandstone
FLIN FLON ARC ASSEMBLAGE
Hidden and Louis formations
Gabbro/diorite
Hidden and Louise basalt and subordinate interflow tuff units
Flin Flon formation
Millrock member
Heterolithic breccia
Rhyolite
VMS deposit: (FF, Main Mine; Tr, Triple 7; C, Callinan)
Blue Lagoon member
Mafic lapilli tuff, breccia
Creighton member
Pillow fragment breccia
Basalt and subordinate interflow tuff units
Fault
Stratigraphic section through Flin Flon horizon volcaniclastic rocks (C. Devine)
Stratigraphic section through Hidden Lake Formation for alteration study (D. Ames)
1:500-scale Flin Flon horizon mapping (Millrock Hill location) (Bailes et al., 2001; Gibson et al., 2001)
1:500-scale hangingwall mapping (N. Tardif)
1:500-scale footwall mapping (Devine, Gibson, Galley, Maclachlan)
Highway
Road
Mine shaft

Figure GS-1-2: Simplified geology of the Flin Flon area, illustrating the location of the various study areas examined for this study (after Bailes and Syme, 1989).

REGIONAL GEOLOGY

There are 27 known VMS deposits within the Paleoproterozoic Flin Flon greenstone belt of the southeastern Reindeer Zone, Trans-Hudson Orogen (Fig. GS-1-1). The VMS-rich greenstone belt consists of a series of accreted oceanic terranes that include arc, back-arc, ocean-floor and successor-arc successions ranging in age from 1.9 to 1.84 Ga (Stern et al., 1995). The VMS deposits are concentrated within the Flin Flon and Snow Lake oceanic-arc assemblages. The present study is located within the Flin Flon arc assemblage, which consists of 1.91 to 1.88 Ga juvenile metavolcanic rocks unconformably overlain by fluvial sedimentary rocks of the ca.1.84 Ga Missi Group. The volcanic rocks consist of basalt, basaltic andesite flows and breccia, and lesser rhyolite flows, all of which were erupted and emplaced in an island-arc–back-arc setting (Syme and Bailes, 1993).

STRATIGRAPHIC DIVISIONS

Informal stratigraphic subdivisions of the volcanic rocks hosting the Flin Flon VMS deposits have been previously proposed by Stockwell (1960), Bailes and Syme (1989), Thomas (1994) and Price (1997). Stratigraphic subdivision has been difficult due to the interlayering of various stratigraphic units, accompanied by rapid and complex facies changes and subsequent overprinting by polyphase fold-fault events. This has resulted in several attempts to define formations (Table GS-1-1).

Table GS-1-1: Stratigraphic nomenclature used for the present study, compared to that used by previous researchers in the area.

		Current Study 2002	Stockwell (1960)	Syme and Bailes (1993)	Thomas (1994)	Price (1997; pers. comm., 2002)
Hangingwall stratigraphy		***Louis fm.***	porphyritic andesite, basalt and flow breccia	Burley Lake basaltic andesite and andesite	Hapnot, Louis Lake basaltic andesite	
		Hidden fm.		Hidden Lake basalt and basaltic andesite	Hangingwall sequence (Hidden Lake basalt)	Hidden Lake fm.; Hanging wall fm; 1920 fm
VMS host stratigraphy	***Flin Flon formation***	***Millrock member***	andesite breccia; quartz porphyry; quartz porphyry breccia	Railway volcaniclastic rocks, "Mine rhyolite", South Main rhyolite domes, South Main pillow fragment breccia	Callinan porphyry, Footwall volcaniclastic rocks	Mine Package fm.
Footwall stratigraphy		***Blue Lagoon member***	porphyritic andesite breccia	plagioclase-phyric mafic volcaniclastic rocks	Footwall volcaniclastic rocks	Hydro Line fm.; Tailings fm.
		Creighton member	andesite, basalt, dacite, and flow breccia			Footwall fm.
		Club member			Club Lake felsic eruptive unit	Club Lake fm.
	Undifferentiated volcanic rocks			South Main basalt	Creighton fm.	

In this study, detailed mapping and stratigraphic analysis have resulted in refinement of the VMS host and footwall stratigraphy (Table GS-1-1). The succession hosting the Flin Flon Main, Callinan and 777 massive sulphide deposits is herein termed the Flin Flon formation (Fig. GS-1-2, GS-1-3). The Flin Flon formation is truncated at the north end of the study area along a disconformable fault contact with the younger Missi Group siliciclastic strata, and is terminated at the south end of the map area by a complex interrelationship between an F_2 anticlinal fold closure and several generations of faulting. The rocks of the Flin Flon formation have been affected mainly by greenschist facies regional metamorphism, with the biotite isograd transecting the formation within a few hundred metres of its northern fault contact.

The Flin Flon formation is subdivided into four mappable, informal members containing units of heterolithic and monolithic breccias, rhyolite flows and domes, and massive and pillowed basalt flows and flow-top breccias. The rock types comprising these members have been described using Fisher's (1966) nongenetic, granulometric classification for volcaniclastic rocks.

Club Lake member

The Club Lake member, the oldest member of the Flin Flon formation (Fig. GS-1-3), consists of four main units: heterolithic basalt±rhyolite breccia; dominantly rhyolite breccia; massive, aphyric rhyolite; and sparsely feldspar-phyric to aphanitic pillowed basalt flows (Fig. GS-1-4, GS-1-5).

The heterolithic basalt breccia (Fig. GS-1-4a) contains subrounded to angular clasts of fine-grained, dark-coloured, feldspar-phyric basalt, sparsely amygdaloidal feldspar-phyric basalt and scoriaceous basalt, and lesser amounts of massive to flow-banded, aphyric, aphanitic rhyolite. Clasts are generally lapilli size but can range up to 85 cm long. Individual depositional units are moderately to poorly sorted, thick- to thin-bedded, matrix-supported tuff and tuff-breccia.

The dominantly monolithic rhyolite breccia contains abundant subangular to angular, aphyric, aphanitic rhyolite clasts and less common, small, aphyric, fine-grained basalt lapilli in a fine-grained mafic matrix. Clasts range up to 52 cm in length. Individual units are clast supported, range from 0.5 to 2.7 m in thickness, and are moderately to well sorted and normally size graded.

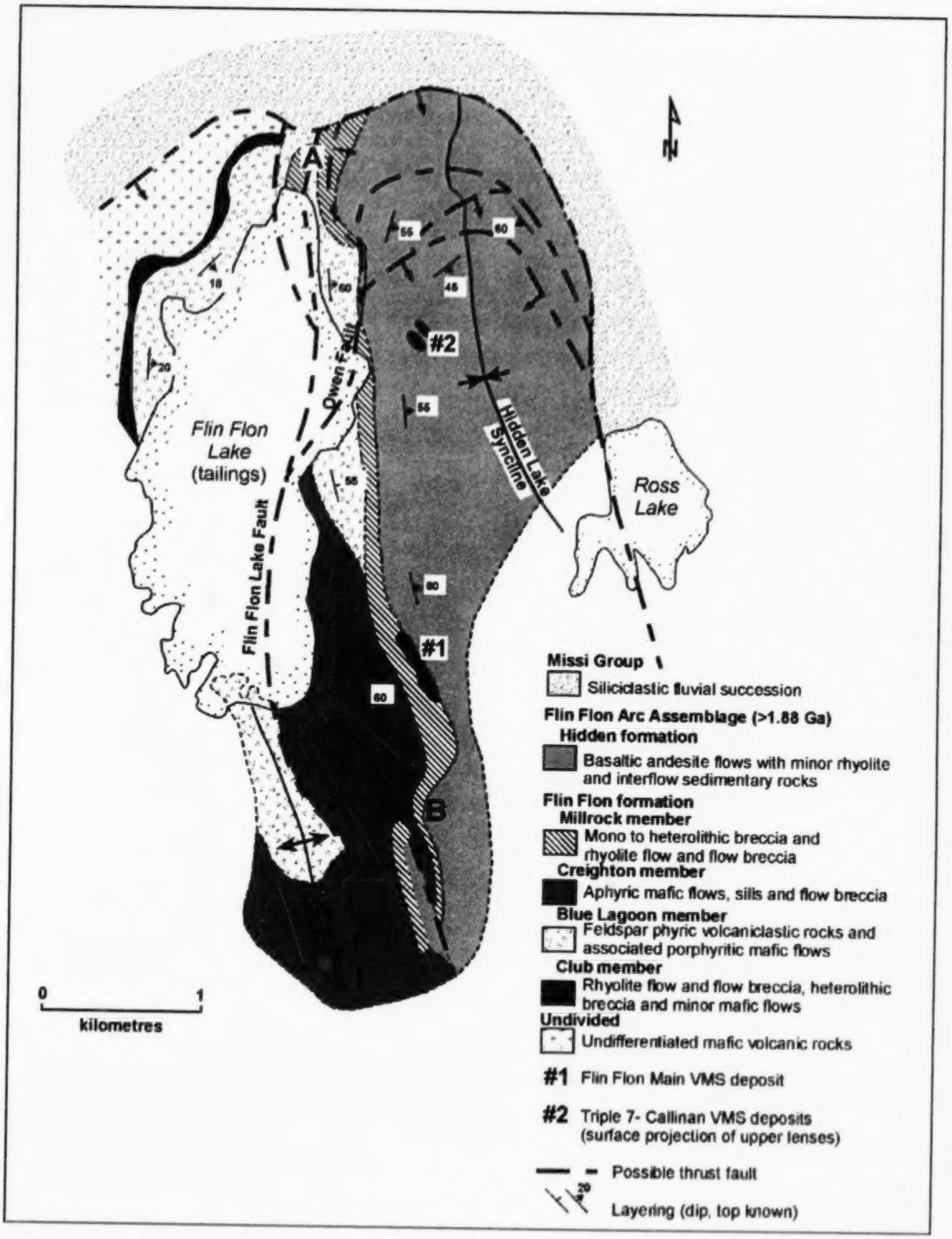

A
B
N
Flin Flon Lake (tailings)
Ross Lake
Flin Flon Lake Fault
Owen Fault
Hidden Lake Syncline
#1
#2
55
60
45
18
20
55
50
80
60
0
1
kilometres
Missi Group
Siliciclastic fluvial succession
Flin Flon Arc Assemblage (>1.88 Ga)
Hidden formation
Basaltic andesite flows with minor rhyolite and interflow sedimentary rocks
Flin Flon formation
Millrock member
Mono to heterolithic breccia and rhyolite flow and flow breccia
Creighton member
Aphyric mafic flows, sills and flow breccia
Blue Lagoon member
Feldspar phyric volcaniclastic rocks and associated porphyritic mafic flows
Club member
Rhyolite flow and flow breccia, heterolithic breccia and minor mafic flows
Undivided
Undifferentiated mafic volcanic rocks
#1 Flin Flon Main VMS deposit
#2 Triple 7- Callinan VMS deposits (surface projection of upper lenses)
Possible thrust fault
29
Layering (dip, top known)

Figure GS-1-3: Preliminary map illustrating the position of proposed early thrust faults and associated repetition of the Flin Flon formation. Structural data for the Hidden Lake formation are from Bailes and Syme (1989). A-B indicates tectonostratigraphic section illustrated in Figure GS-1-6.

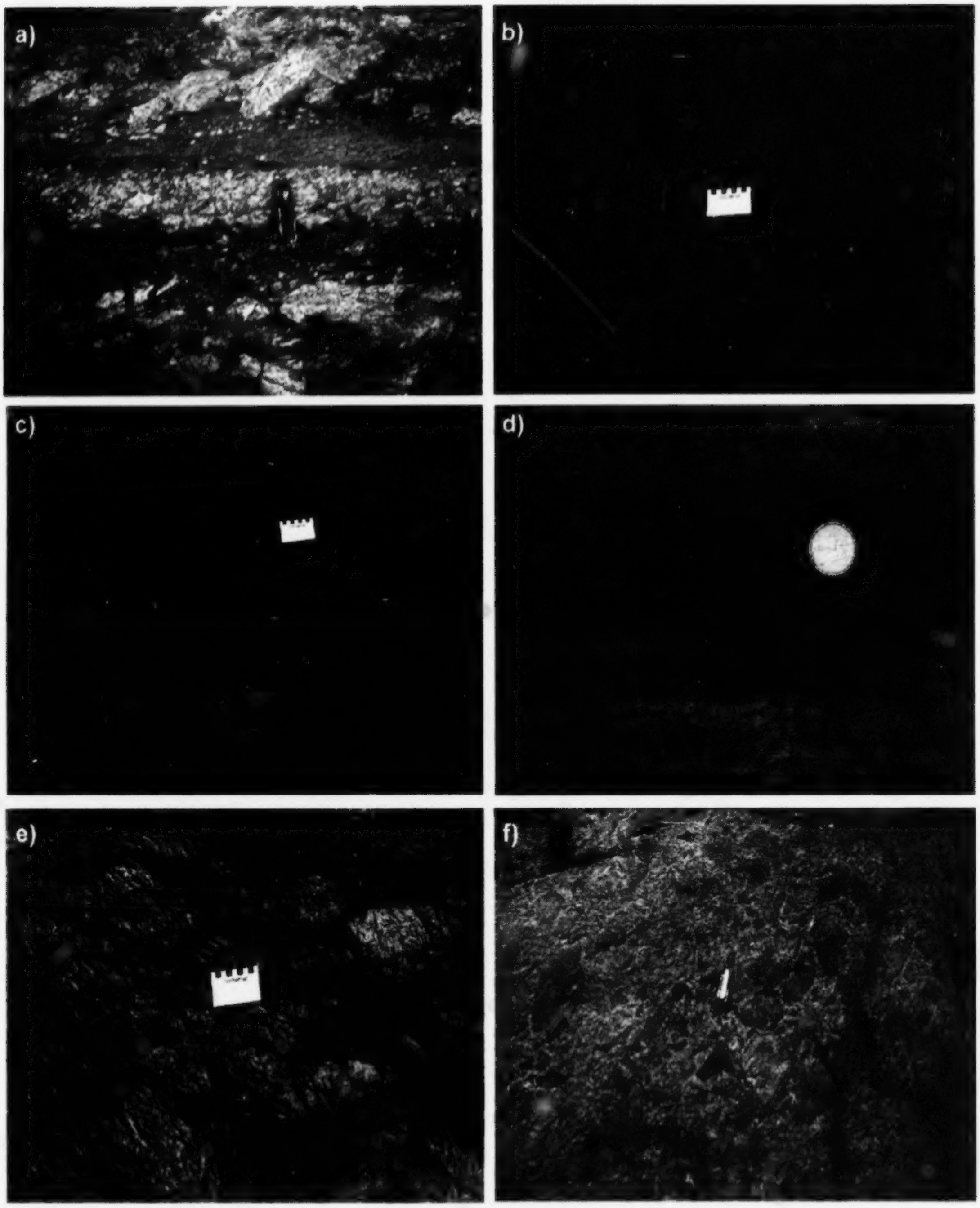


Figure GS-1-4: a) Beds of monolithic rhyolite tuff-breccia interbedded with layers of mafic tuff and lapilli tuff; knife is 9 cm in length. b) Heterolithic crystal lapilli-tuff with basalt clasts and abundant feldspar phenoclasts in the matrix. c) Amoeboid basalt breccia with an individual amoeboid-shaped clast at centre. d) Mafic bedded tuff with crosslaminations. e) Rhyolite-dominated heterolithic breccia. f) Heterolithic basalt tuff-breccia.

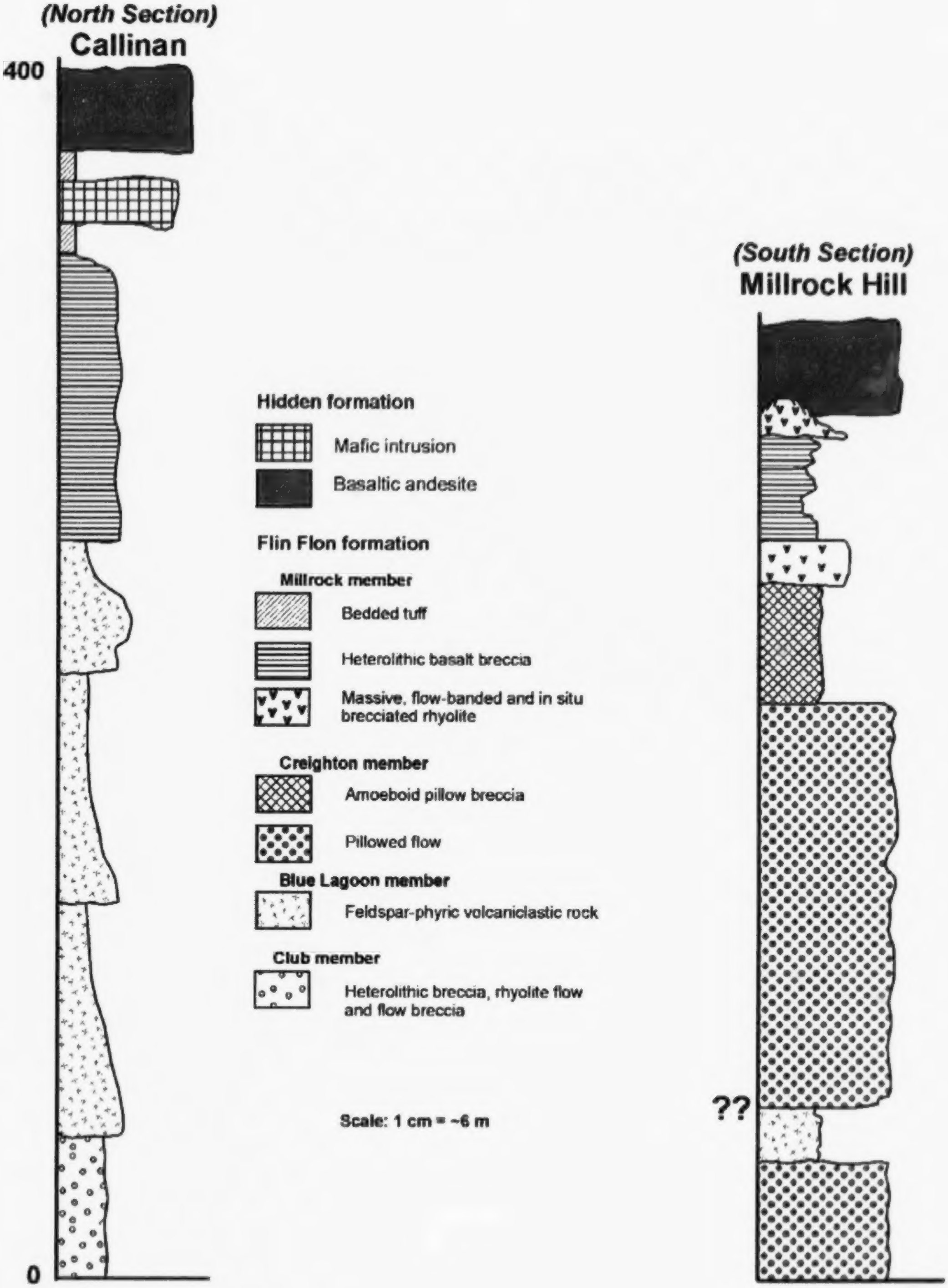

(North Section)
Callinan
400
0
(South Section)
Millrock Hill
??
Hidden formation
Mafic intrusion
Basaltic andesite
Flin Flon formation
Millrock member
Bedded tuff
Heterolithic basalt breccia
Massive, flow-banded and in situ brecciated rhyolite
Creighton member
Amoeboid pillow breccia
Pillowed flow
Blue Lagoon member
Feldspar-phyric volcaniclastic rock
Club member
Heterolithic breccia, rhyolite flow and flow breccia
Scale: 1 cm = ~6 m

Figure GS-1-5: Schematic stratigraphic sections from the volcaniclastic-rich northern and eruptive-dominated southern parts of the Flin Flon formation.

The rhyolite is massive, aphyric, aphanitic and locally flow banded. This unit has a minimum thickness of 5 m and is in sharp, flow-banded contact with volcaniclastic rocks. Conformable but sharp contacts between massive rhyolite and overlying volcaniclastic rocks suggest emplacement of the former as either a flow or a sill.

Blue Lagoon member

The Blue Lagoon member conformably overlies the Club Lake member and is a distinctive unit characterized by varying amounts and sizes of feldspar crystals that may constitute 5 to 25% of the matrix and that range in size from 0.2 to 1 cm (Fig. GS-1-3, GS-1-5). It contains several subsidiary rock types, including rhyolitic tuff, heterolithic crystal lithic basaltic breccia, and feldspar-phyric massive and pillowed basalt flow and flow breccia.

The rhyolitic tuff is a thin to medium planar-bedded unit containing less than 5% quartz crystals up to 3 mm in size.

The heterolithic basaltic volcaniclastic breccia units (Fig. GS-1-4b) consist of crystal tuff, crystal lapilli-tuff, crystal lapillistone, crystal tuff-breccia and crystal-rich block breccia. Individual units have normal to reverse size-grading, are dominantly matrix supported (approx. 70 % matrix), are poorly to well sorted and have thicknesses ranging from 0.1 to 8.2 m. Although most beds have a feldspar-rich matrix, some intercalated beds have little to no feldspar in the matrix.

Many different clast textures are observed in the heterolithic basaltic breccia units. Amygdaloidal clasts are aphyric or feldspar phyric, contain 5 to 50% quartz- and feldspar-filled amygdules, and range in size from 2.1 to 41.6 cm. Amygdaloidal clasts range in colour from white to grey to pink-brown, and are generally subrounded and oriented parallel to the strike of the volcaniclastic beds. Wispy clasts differ from amygdaloidal clasts in their irregular, wispy shape and fine-grained texture. Wispy clasts contain 5 to 15% amygdules, are generally subangular (irregular) to angular, range up to 13 cm in size and contain 5 to 15% feldspar phenocrysts.

Creighton member

The contact between the Blue Lagoon member and the Creighton member is observed on an island in the tailings pond, with the former clearly underlying the latter. To the southeast, it appears that the contact relationship is reversed, suggesting contemporaneous deposition of the two members (Fig. GS-1-3). The Creighton member rapidly thickens to the south to become the dominant footwall lithology below the Flin Flon deposit (Fig. GS-1-3), where it includes a unit previously identified as the South Main basalt (Syme and Bailes, 1993). The member consists of aphyric flows and sills of basalt and amoeboid basalt breccias (Fig. GS-1-3c). The latter are clast-supported, moderately to poorly sorted tuff-breccia units, and consist of scoriaceous, aphyric basalt clasts with 40% amygdules and sparsely amygdaloidal basalt clasts with 10 to 20% amygdules. Clasts range from 25 to 95 cm in size and have distinct chilled margins and well-preserved, irregular, amoeboid shapes.

Millrock member

The uppermost member of the Flin Flon formation unconformably and locally conformably overlies the previously deposited footwall strata. This is believed to be a function of both rapid tilting of the underlying strata during emplacement of the Millrock member (Syme and Bailes, 1993) and localized erosion due to channellized mass flow. The Millrock member hosts the Flin Flon, Callinan and 777 VMS deposits, and includes heterolithic and monolithic footwall breccias, aphyric to quartz-feldspar–phyric rhyolite and contemporaneous volcaniclastic rocks (Fig. GS-1-3). The Railway heterolithic volcaniclastic rocks of Bailes and Syme (1989) are also included in this member.

The bedded tuff unit (Fig. GS-1-4d), located at the top of the member, contains thin beds of ash-sized material that are locally sulphide stained. The tuff, although mainly planar bedded, is locally crosslaminated and shows soft-sediment slump structures. It locally contains scoriaceous basalt, feldspar-phyric basalt and aphyric rhyolite clasts; the matrix may contain minor amounts of feldspar and quartz crystals 1 to 2 mm in size.

Monolithic, coherent rhyolite ranges from massive to flow banded to in situ brecciated, with quartz crystals that range in size from 3 to 5 mm. Jigsaw-fit clasts in the breccia are angular to subangular and do not appear to be transported.

Monolithic rhyolite breccias range in size from lapillistone to blocky breccia. This clast-supported unit has a rhyolitic matrix and contains subangular to angular rhyolite clasts with 2 to 5 mm quartz crystals and less than 5% amygdaloidal basaltic clasts. This unit generally fines upwards and has bed thicknesses ranging from 1.2 to 4.5 m.

Rhyolite-dominated, heterolithic breccia units (Fig. GS-1-3e) consist of clast-supported lapillistone and tuff-breccia, with an ash-sized mafic matrix. Clasts are elongate, rounded to angular in shape and range from centimetres to metres in size. Clast types include quartz-phyric rhyolite, sparsely amygdaloidal basalt and scoriaceous, aphyric basalt. Beds range from 0.4 to 9.9 m in thickness.

Basalt-dominated heterolithic breccia units, including lapilli-tuff, lapillistone and tuff-breccia, are clast supported with rounded to angular, sparsely amygdaloidal and scoriaceous, aphyric basalt clasts, and quartz-phyric rhyolite clasts in a fine, ash-sized matrix. Bed thicknesses range from 0.2 to 4.6 m.

Monolithic basaltic lapilli-tuff to lapillistone units contain subrounded to angular clasts of scoriaceous to sparsely amygdaloidal basalt up to 30 cm in size. This matrix-supported unit fines upwards and has beds ranging from 0.25 to 5 m in thickness.

The heterolithic basaltic breccia units (Fig. GS-1-3f) comprise lapilli-tuff to tuff-breccia with subrounded to angular clasts. These clasts include sparsely amygdaloidal, amygdaloidal, scoriaceous, aphyric basalt; wispy-shaped, aphanitic, aphyric basalt; feldspar-phyric basalt; fine-grained gabbro; and rare sulphide (sphalerite) clasts (the latter only observed underground), all in a fine-grained, mafic matrix. Depositional units range from 0.4 to 6 m in thickness, and are dominantly clast supported (70–80% clasts) and well to poorly sorted. Clasts range from 0.2 to 80 cm in size, and the unit fines upward to the ash-sized bedded tuff at the top of the VMS host member.

In heterolithic basalt breccia units, aphyric amygdaloidal basalt clasts are fine grained, subrounded to angular and variably coloured, from grey to pinkish grey to white. Amygdule content ranges from 2 to 30%, and averages 15%. Amygdaloidal feldspar-phyric clasts are generally highly amygdaloidal, more so than the aphyric clast type. Amygdule content ranges from 5 to 45% (30% average). Feldspar crystals range from 1 to 10% and are 1 mm in size. These fragments are subrounded, with some angular and rounded clasts as well. The common colour is white or pinkish grey, and most clasts are lapilli sized. Wispy clasts are fine grained, dark grey in colour, have irregular, angular shapes with a platy appearance, contain 2 to 10% amygdules, and are feldspar phyric (1–2%). Gabbroic clasts constitute less than 1% of the entire clast population. They are pink-brown in colour, are rounded to subrounded, have mafic (?pyroxene) crystals, are sparsely amygdaloidal and range from 3.5 to 4.6 cm in size. Sphalerite and pyrite clasts observed underground at 777 are a brassy brown colour and highly attenuated, with lengths of 20 to 60 cm and widths of only 1 cm.

SUBVOLCANIC INTRUSIVE ROCKS

The Flin Flon formation volcaniclastic strata and subordinate flows are transected by dense swarms of subvolcanic mafic dikes. These dike swarms appear to have been active during emplacement of the Flin Flon formation, but also include feeder dikes for the overlying Hidden Lake formation. Many of the early-stage dikes have peperitic margins, and are affected by zones of intense, fracture-controlled alteration. The immediate host volcaniclastic strata are also commonly silicified, chloritized and/or altered to amphibole and clinozoisite with accompanying sulphide staining. In some cases, the dike swarms are so intense that they can only be differentiated from one another by the presence of chilled margins and small screens of highly altered host strata. These are very similar situations to those described for sheeted dike swarms in ophiolite complexes (Lydon and Jamieson, 1984 and references therein).

IMPLICATIONS FOR EMPLACEMENT

It is evident from the above descriptions of volcaniclastic rocks that the Flin Flon formation and its members form a complex succession of heterolithic and monolithic, felsic and mafic volcaniclastic rocks and flows. The schematic reconstructed cross-section in Figure GS-1-6 illustrates the range in thickness of the different members of the Flin Flon formation and how they have been emplaced within a structurally controlled basin, as originally interpreted by Syme and Bailes (1993). The bedded tuff deposits are interpreted to have been emplaced by low-concentration mass flows (turbidity flows or currents) or suspension deposits where ash-sized material is deposited from the tail end of a flow. The coarser breccias are interpreted to have been emplaced as channellized, high-concentration mass flows carrying large amounts of material downslope en masse. The chaotic nature of the VMS footwall succession is indicative of a high-energy, unstable regime typical of rapid basin development with associated faulting. The occurrence of intense dike swarms is supportive of the presence of synvolcanic faults developing in a localized rift environment. The recognition of these dike swarms will assist in delineating the focal points for hydrothermal activity for both known and unknown VMS deposits.

DISTRIBUTION OF MEMBERS AND TENTATIVE STRUCTURAL INTERPRETATION

Previous work by Stockwell (1960), Bailes and Syme (1989), Price (1997) and Thomas (1994) indicates that the Flin Flon formation has been deformed by polyphase folding and extensive faulting, including thrust faults. The

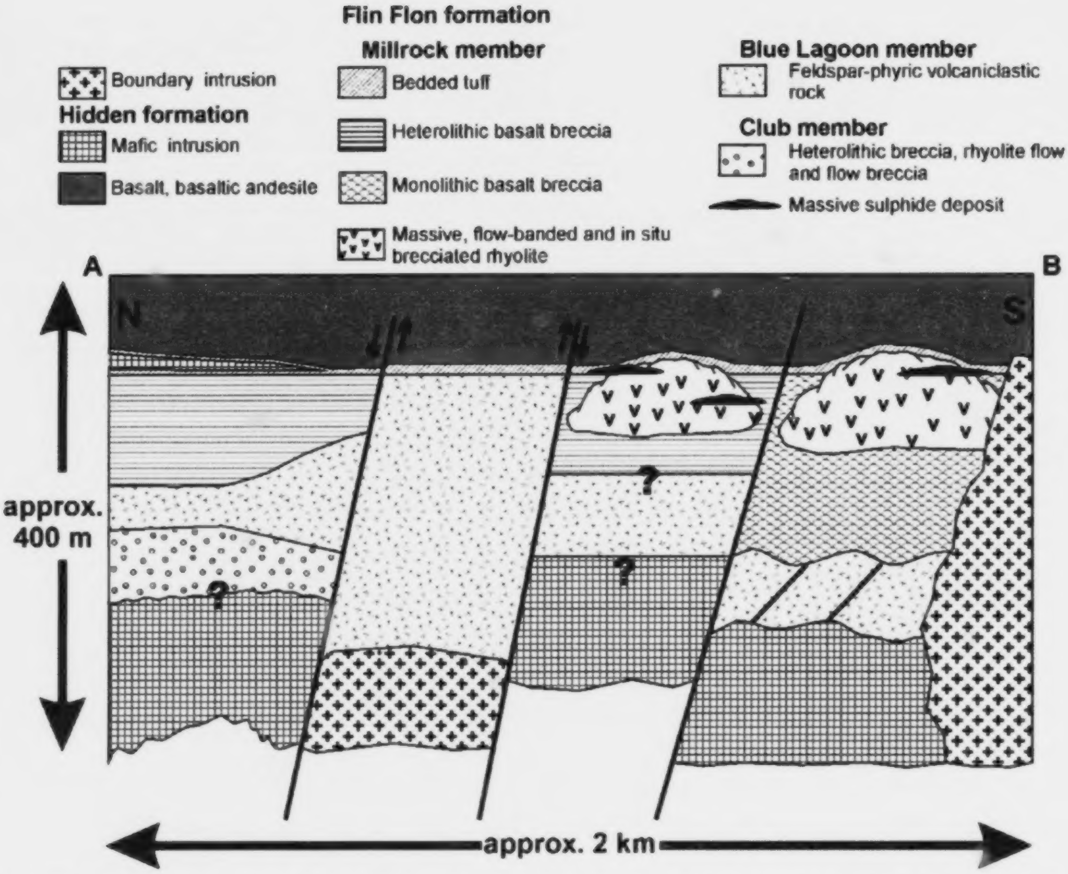

Flin Flon formation
Millrock member
Blue Lagoon member
Boundary intrusion
Hidden formation
Mafic intrusion
Basalt, basaltic andesite
Bedded tuff
Heterolithic basalt breccia
Monolithic basalt breccia
Massive, flow-banded and in situ brecciated rhyolite
Feldspar-phyric volcaniclastic rock
Club member
Heterolithic breccia, rhyolite flow and flow breccia
Massive sulphide deposit
A
B
N
S
approx. 400 m
?
?
?
approx. 2 km

Figure GS-1-6: Schematic tectonostratigraphic section through the Flin Flon formation, extending south from the northern termination of the formation against the Club Lake Fault. Location of section indicated by A-B on Figure GS-1-3.

earliest foliation (S_1), only observed in the closures of F_2 folds, may be axial planar to an earlier set of F_1 isoclinal folds. The most prominent penetrative fabric (S_2) is axial planar to northerly-trending, southeast-plunging F_2 folds, such as the Beaver Road anticline and Hidden Lake syncline (Stockwell, 1960; Price, 1997; Fig. GS-1-4). These, along with northerly-trending shear and fault zones, such as the Flin Flon Lake and Owen faults, dominate the structure of the Flin Flon area. The Flin Flon, Callinan and 777 VMS deposits, which have been interpreted to occur on the east limb of the Flin Flon anticline, are elongate parallel to a shallow (37°) southeast-plunging extensional fabric that is collinear with the F_2 fold axes and manifested by the elongation of amygdules, pillows and clasts.

Although previous work has clearly defined the Hidden Lake syncline (Bailes and Syme, 1989), the location of the north extension of the Beaver Road anticline beneath Flin Flon Lake and the west limb of this F_2 structure remained poorly constrained and uncertain. However, the distribution of the Flin Flon formation, particularly the four members that constitute this formation as illustrated in Figure GS-1-4, indicates that the Flin Flon anticline is structurally repeated by faulting and that the lower two members of the formation, the Club and Blue Lagoon members, occur on the west side of Flin Flon Lake where they dip shallowly to the east. The northerly-trending and east-dipping faults responsible for this structural repetition are interpreted to be thrust faults, based on 1) their attitude, which is typically parallel to the strike of the enclosing units but more steeply dipping; and 2) repetition of units and members, in both surface outcrops and drill core, which clearly places older members on top of younger members and, in places, the Flin Flon formation upon younger Missi Group sedimentary rocks west and north of Flin Flon Lake. Clearly, the nature, orientation and kinematics of these northerly-trending faults, which were first recognized by Stockwell (1960) to repeat basalt flows of the Hidden Lake formation, must be carefully documented and evaluated. However, a tentative structural interpretation based on the new stratigraphy and mapping places the Blue Lagoon member and, more importantly, the VMS-hosting Millrock member within structurally stacked panels below, and on the east side of, Flin Flon

Lake. This stratigraphic and structural interpretation has significant ramifications for exploration and is in the process of being refined and evaluated.

CONCLUSIONS AND FUTURE WORK

Volcaniclastic rocks of the VMS-hosting Flin Flon formation are very complex heterolithic units that are divisible into four distinctive and mappable members. This new stratigraphic subdivision, which clearly defines the characteristics of the volcaniclastic rocks hosting the VMS deposits at Flin Flon, allows their recognition elsewhere and may prove to be a powerful tool for tracing volcanic stratigraphy with the potential to host more VMS mineralization. The stratigraphy has also facilitated recognition of thrust faults, which have repeated the formation and also, perhaps, the contained VMS mineralization. Future work will use the detailed clast count data to determine possible emplacement mechanisms for the volcaniclastic rocks, by examining the stratigraphic distribution of the size and percentage of clasts. In addition, geochemistry and petrography of the clasts will provide evidence for the provenance of the various units that constitute this formation.

ACKNOWLEDGMENTS

Funding for this study was provided through the Geological Survey of Canada's Targeted Geoscience Initiative and Laurentian University. Tom Lewis, Edgar Wright and all the staff at Hudson Bay Exploration and Development Co. Ltd. are thanked for providing maps, references and unlimited access to their knowledge and company properties. The authors would especially like to thank J.J. O'Donnell and Chris Hunter at Hudson Bay Mining and Smelting Co. Ltd. for their time and patience with the underground component of this study. Thanks also go to Eric Syme (Manitoba Geological Survey), Gary Delaney (Saskatchewan Energy and Mines) and Doreen Ames (Geological Survey of Canada), who have provided invaluable time, knowledge and helpful suggestions throughout this study. Data and sample collection in the field could not have been accomplished without the help of Lindsay Moeller (University of Saskatchewan), Patrick Schmidt, Ben Vanden Berg (GSC), and Brad Harvey (GSC).

REFERENCES

Bailes, A.H. and Syme, E.C. 1989: Geology of the Flin Flon–White Lake area; Manitoba Energy and Mines, Minerals Division, Geological Report GR87-1, 313 p.

Bailes, A.H., Bray, D. and Syme, E.C. 2001: Geology of the South Main shaft area, Flin Flon (part of NTS 63K/13SW); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map 2001F-2, scale 1:500.

Fisher, R.V. 1966: Rocks composed of volcanic fragments; Earth Science Reviews, v.1, p. 287–298.

Gibson, H.L., Bailes, A.H., Tourigny, G. and Syme, E.C. 2001: Geology of the Millrock Hill area, Flin Flon (parts of NTS 63K/13SW, /12NW); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map 2001F-1, scale 1:500.

Lydon, J.W. and Jamieson, H.E. 1984: The generation of ore-forming hydrothermal solutions in the Troodos ophiolite complex: some hydrodynamic and mineralogical considerations; *in* Current Research, Part A, Geological Survey of Canada, Paper 84-1A, p. 617–625.

Price, D. 1997: Flin Flon–Creighton generalized geological map (1:10 000); Hudson Bay Exploration and Development Co. Ltd., internal map.

Stern, R.A., Syme, E.C., Bailes, A.H. and Lucas, S.B. 1995, Paleoproterozoic (1.90–1.86 Ga) arc volcanism in the Flin Flon Belt, Trans-Hudson Orogen, Canada; Contributions to Mineralogy and Petrology, v. 119, p. 117–141.

Stockwell, C.H. 1960: Flin Flon–Mandy area, Manitoba and Saskatchewan; Geological Survey of Canada, Map 1078A, scale 1:12 000, with descriptive notes.

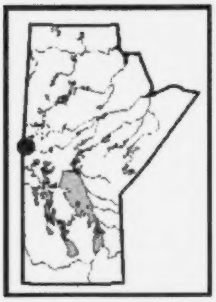
Syme, E.C. and Bailes, A.H. 1993: Stratigraphic and tectonic setting of volcanogenic massive sulfide deposits, Flin Flon, Manitoba; Economic Geology, v. 88, p. 566–589.

Syme, E.C., Bailes, A.H. and Lucas, S.B. 1996: Tectonic assembly of the Paleoproterozoic Flin Flon belt and setting of VMS deposits; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Winnipeg, Manitoba, May 27–19, 1996, Field Trip guidebook B1, 131 p.

Thomas, D.J. 1994: Stratigraphic and structural complexities of the Flin Flon mine sequence; *in* Summary of Investigations 1994, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 94-4, p 3–10.

GS-2 GEOLOGY AND HYDROTHERMAL ALTERATION OF THE HANGING WALL STRATIGRAPHY TO THE FLIN FLON–777–CALLINAN VOLCANOGENIC MASSIVE SULPHIDE HORIZON (NTS 63K12NW AND 13SW), FLIN FLON AREA, MANITOBA

by D.E. Ames[1], N. Tardif[2], K. MacLachlan[3] and H.L. Gibson[2]



Ames, D.E., Tardif, N., Maclachlan, K. and Gibson, H.L. 2002: Geology and hydrothermal alteration of the hanging wall stratigraphy to the Flin Flon–777–Callinan volcanogenic massive sulphide horizon (NTS 63K12NW and 13SW), Flin Flon area, Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 20-34.

SUMMARY

The objective of this subproject of the Flin Flon Targeted Geoscience Initiative is to gain a better understanding of the nature and distribution of hydrothermal alteration within the hanging wall strata, herein called the Hidden formation, to the Flin Flon–777–Callinan volcanogenic massive sulphide (VMS) deposits of the Paleoproterozoic Flin Flon Belt.

Important findings to date from this study include

- recognition of extensive zones of hydrothermal alteration, within the hanging wall strata, that include both distal and proximal alteration facies;
- definition of two distinct, synvolcanic dike swarms within the Hidden and Louis formations, one of which includes felsic dikes; dike swarms are important for localizing hydrothermal fluid upflow zones; and
- identification of a rhyolite flow unit with associated sulphidic sedimentary rocks, called the 'Tower member', at the top of the Hidden formation; this increases the exploration potential for another VMS-bearing horizon in the Flin Flon area, at the upper contact of the Hidden formation with the Louis formation.

INTRODUCTION

The Flin Flon Targeted Geoscience Initiative (FFTGI) is a three-year (2000–2003) federal initiative designed to develop new criteria to assist exploration and mining companies in increasing ore reserves, thereby stabilizing the economy of this northern mining community. The project objectives are to 1) increase the understanding of the volcanic and hydrothermal history of the western Paleoproterozoic Flin Flon volcanic belt with respect to formation of volcanogenic massive sulphide (VMS) deposits; and 2) assist the development of exploration strategies that support the discovery of new VMS deposits (Galley and Bailes, 2001).

The premise of this study is that most VMS hydrothermal systems result in alteration of not only the strata underlying the massive sulphide deposit, but may also affect overlying strata. This hanging wall alteration may be a function of one of two processes. The first is continuation of the hydrothermal fluid flow responsible for the formation of the VMS deposit during the progressive burial of the deposit by volcanic flows and sediments. There are many examples of this process in the Noranda camp, resulting in either zones of alteration, extending for up to 500 m above a known VMS deposit (e.g., the Ansil deposit; Riverin et al., 1990), or stacked orebodies formed at successive seawater-rock interfaces (e.g., the Amulet deposits; Gibson and Watkinson, 1990). The second process involved in the generation of hanging wall alteration is the formation of an entirely new subseafloor hydrothermal system, triggered by the cooling of a thick pile of volcanic flows. Whereas the continuation of an existing hydrothermal system into the hanging wall would result in the formation of discrete alteration pipes, the generation of a new hydrothermal system should result in broader, semiconformable alteration with associated, discrete, disconformable alteration pipes. Both cases can result in the periodic formation of sulphidic sedimentary, or 'exhalite', units (Franklin et al., 1981).

The Flin Flon–777–Callinan VMS horizon provides an ideal setting for a hanging wall alteration study, due to the relative compositional homogeneity and 600–700 m thickness of the hanging wall basalt succession. The study involves detailed stratigraphic examination and sampling of the Hidden formation along its 5000 m known strike length, as well as traverses within a correlative mafic-flow succession farther west in Saskatchewan, where the VMS-bearing succession is believed to be duplicated due to folding (Fig. GS-2-1). Flow-facies variations were defined along evenly spaced sections. In addition, the presence and type of interflow sedimentary rocks and the nature and extent of alteration were documented along these sections.

---

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

[2] Mineral Exploration Research Centre, Department of Earth Sciences, Laurentian University, Sudbury, Ontario P3E 2C6

[3] Saskatchewan Geological Survey, Saskatchewan Industry and Resources, 2101 Scarth Street, Regina, Saskatchewan S4P 3V7

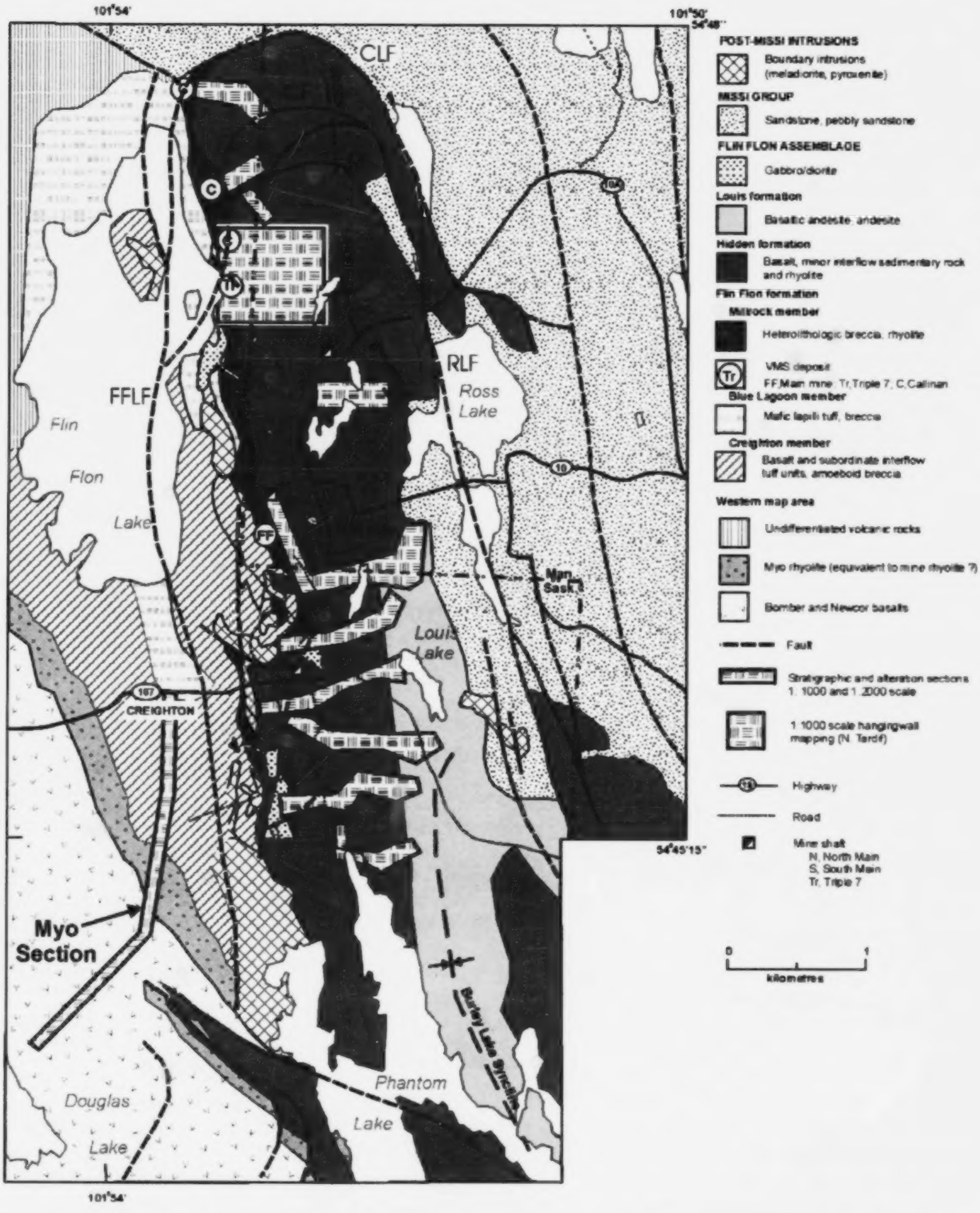

101°54'
101°50'
54°48''
CLF
CF
FFLF
RLF
Flin
Flon
Lake
Ross
Lake
Louis
Lake
Phantom
Lake
Douglas
Lake
Myo
Section
CREIGHTON
167
106
10
FF
C
Tr
Mrn
Sask
Burley Lake Syncline
54°45'15''
101°54'
POST-MISSI INTRUSIONS
Boundary intrusions (meladiorite, pyroxenite)
MISSI GROUP
Sandstone, pebbly sandstone
FLIN FLON ASSEMBLAGE
Gabbro/diorite
Louis formation
Basaltic andesite, andesite
Hidden formation
Basalt, minor interflow sedimentary rock and rhyolite
Flin Flon formation
Millrock member
Heterolithologic breccia, rhyolite
VMS deposit
FF,Main mine; Tr,Triple 7; C,Callinan
Blue Lagoon member
Mafic lapilli tuff, breccia
Creighton member
Basalt and subordinate interflow tuff units, amoeboid breccia
Western map area
Undifferentiated volcanic rocks
Myo rhyolite (equivalent to mine rhyolite ?)
Bomber and Newcor basalts
Fault
Stratigraphic and alteration sections 1: 1000 and 1: 2000 scale
1: 1000 scale hangingwall mapping (N. Tardif)
Highway
Road
Mine shaft
N, North Main
S, South Main
Tr, Triple 7
0
1
kilometres

Figure GS-2-1: Simplified geology of the Flin Flon block, showing the location of detailed traverses in the hanging wall of the Flin Flon-777-Callinan VMS horizon. Abbreviations: CLF, Club Lake Fault; CF, Catharine Fault; FFLF, Flin Flon Lake Fault; RF, Railway Fault; RLF, Ross Lake Fault.

During the 2001 and 2002 field seasons, mapping of the hanging wall stratigraphy to the Flin Flon mine horizon consisted of 1) ten traverses, mapped at 1:1000 and 1:2000 scale, extending from the Club Lake Fault in the north to Phantom Lake in the south; 2) a 1:2000-scale section through the western, southwest-younging limb of the Beaver Road anticline, from Myo Lake towards Douglas Lake (K. Maclachlan); and 3) a detailed 1:1000-scale study above the 777 orebody (M.Sc. thesis, N. Tardif, Laurentian University; Fig. GS-2-1).

The Myo Lake section (Fig. GS-2-1) is thought to be broadly correlative with the east-younging limb that hosts the Flin Flon VMS deposits. In particular, the Myo rhyolite (Thomas, 1990) is thought to be correlative with the Flin Flon VMS-bearing horizon (K. Gilmore, pers. comm., 2002).

GEOLOGY OF THE HANGING WALL STRATIGRAPHY TO THE FLIN FLON–777–CALLINAN VMS HORIZON

One of the objectives of the FFTGI is to develop a 1:10 000-scale geological compilation of the Flin Flon structural block, in order to standardize unit correlations as defined by various workers, including Stockwell (1960), Bailes and Syme (1989), Thomas (1990) and Hudson's Bay Exploration and Development Co. Ltd. (HBED). An early result of this synthesis is to define the immediate hanging wall basalt succession to the Flin Flon–777–Callinan VMS deposits as the Hidden formation, and the VMS hostrock package and underlying volcaniclastic and eruptive units as the Flin Flon formation (Fig. GS-2-1). The Hidden formation contains an unnamed lower member, the '1920 member', the Reservoir member and, at its top, the Tower member. For the purposes of this study, it is assumed that the basalt stratigraphically above the Myo rhyolite is equivalent to the Hidden formation.

Hidden formation

The Hidden formation is dominated by basaltic andesite flows, with subordinate interflow sediment and rhyolite. Stratigraphic tops are to the east and southeast in the main mine package, the tops indicators including distribution of amygdules, gas cavities and pipe vesicles, re-entrant selvages, pillow morphology and stacking, and graded beds, channels and load casts of the sedimentary rocks. The apparent thickness is variable due to structural complications caused by D_2 folding at both the lower contact, particularly in the Millrock Hill–Phantom Lake area to the south, and the upper contact in the Railway Fault–Ross Lake area in the central part (Fig. GS-2-1). The lower contact in the southern area is duplicated by D_1 thrust faults focused along interflow sediment horizons. The exposed thickness of the Hidden formation varies from approximately 650 m in the area between the 777 and Flin Flon deposits, to 880 m south of the Flin Flon deposit, to 400 m just north of Phantom Lake. Along the west shore of Phantom Lake, Stockwell (1960) showed the mafic flows of the Hidden formation thinning out and interlayering with mafic volcaniclastic units, similar to those observed as interflow sedimentary rocks farther north in the study area.

The lower mafic flows of the Hidden formation are in contact with heterolithic breccia and rhyolite of the Flin Flon formation. The upper contact of the Hidden formation is defined by the first appearance of pyroxene-plagioclase–phyric basalt of the Louis formation. The upper contact is further defined by the presence of rhyolite flows, and related talus debris and sulphidic mafic and felsic interflow sedimentary rocks, which form the Tower member of the Hidden formation (Fig. GS-2-2, GS-2-3).

Descriptions of the Hidden formation are given for the North Callinan, 777, Flin Flon, Phantom Lake and Myo Lake sections.

North Callinan section

The northernmost contact of the Hidden formation is bordered by younger Missi Group formation along the D_1 Club Lake Fault. In this northern third of the study area, the Hidden formation is affected by numerous, refolded, D_1 thrust faults (Fig. GS-2-1). A 200 m thick gabbro intrudes the base of the sequence and contains numerous rafts of basalt, sedimentary rocks and mafic dikes. Removing this intrusion, the lower 110–160 m section of the Hidden Lake succession consists of a pale grey weathering icelandite, informally known as the '1920 member' (D. Price, pers. comm., 2002) This distinctive unit is approximately 60 m thick and has acicular amphibole needles and 20% feldspar microphenocrysts, along with large gas cavities that are the focus for intense epidote-amphibole-sulphide alteration. The upper contact of the '1920 member' is peperitic into fine-grained mafic tuff, forming extensive, altered breccia zones up to 30 m wide. The peperite suggests that the unit flowed and/or intruded into a sequence of fine-grained, mafic volcaniclastic rocks and siltstone at shallow levels. The mafic volcaniclastic rocks contain abundant sedimentary structures, such as normal grading, channels, dropstones and load casts. The mafic volcaniclastic rock–siltstone occurs in varying amounts in the basal section of the Hidden formation, along its entire 5000 m strike length, as remnants

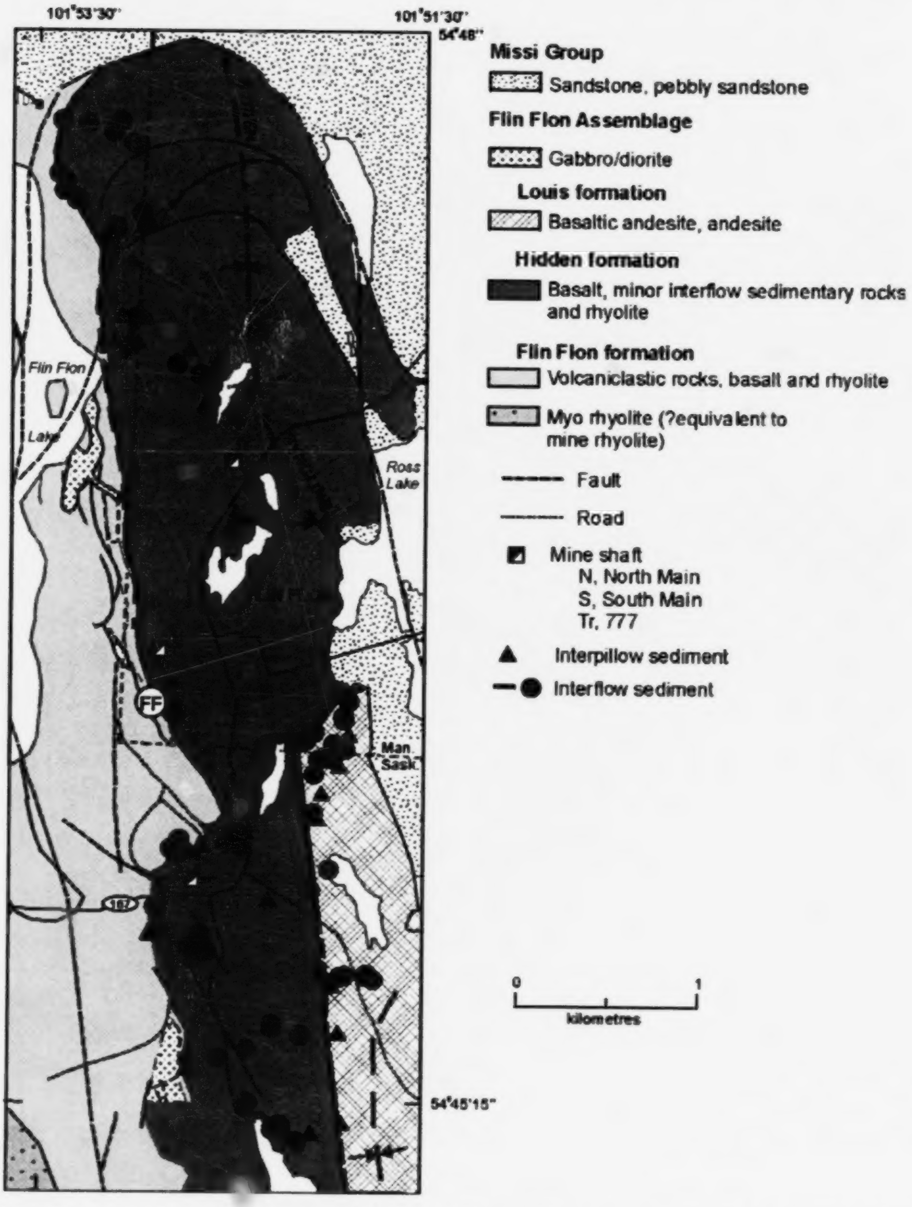

101°53'30"
101°51'30"
54°48"
Missi Group
Sandstone, pebbly sandstone
Flin Flon Assemblage
Gabbro/diorite
Louis formation
Basaltic andesite, andesite
Hidden formation
Basalt, minor interflow sedimentary rocks and rhyolite
Flin Flon formation
Volcaniclastic rocks, basalt and rhyolite
Myo rhyolite (?equivalent to mine rhyolite)
Fault
Road
Mine shaft
N, North Main
S, South Main
Tr, 777
Interpillow sediment
Interflow sediment
Flin Flon
Lake
Ross
Lake
FF
Man.
Sask.
10
54°45'15"
0
1
kilometres

Figure GS-2-2: Distribution of interflow sedimentary rocks in the Hidden and Louis formations; note the concentration of sedimentary rocks as interflow, interpillow and peperite near the base of the two formations. See Figure GS-2-1 for traverse locations.

between pillows and as more intact interflow intervals. In most cases, these mafic sedimentary rocks are the focus for much of the alteration observed within the Hidden formation.

Above this basal section are 10 to 65 m thick flows of plagioclase-phyric, sparsely plagioclase-phyric and aphyric basalt flows that are dominantly pillowed, with pillow size being moderate (at 45 to 70 cm). Massive flows display laminar cooling cracks, 5 to 20 cm gas cavities at the top, and elutriation pipes at the lower contact due to extrusion into wet, unconsolidated sediment. The dominant trend of comagmatic mafic dikes is 145° which is subparallel to the plunge of the D_2 folds. The north Callinan section contains subequal proportions of intrusive and extrusive mafic rocks (45%) and 10% sediment (>60 m cumulative thickness).

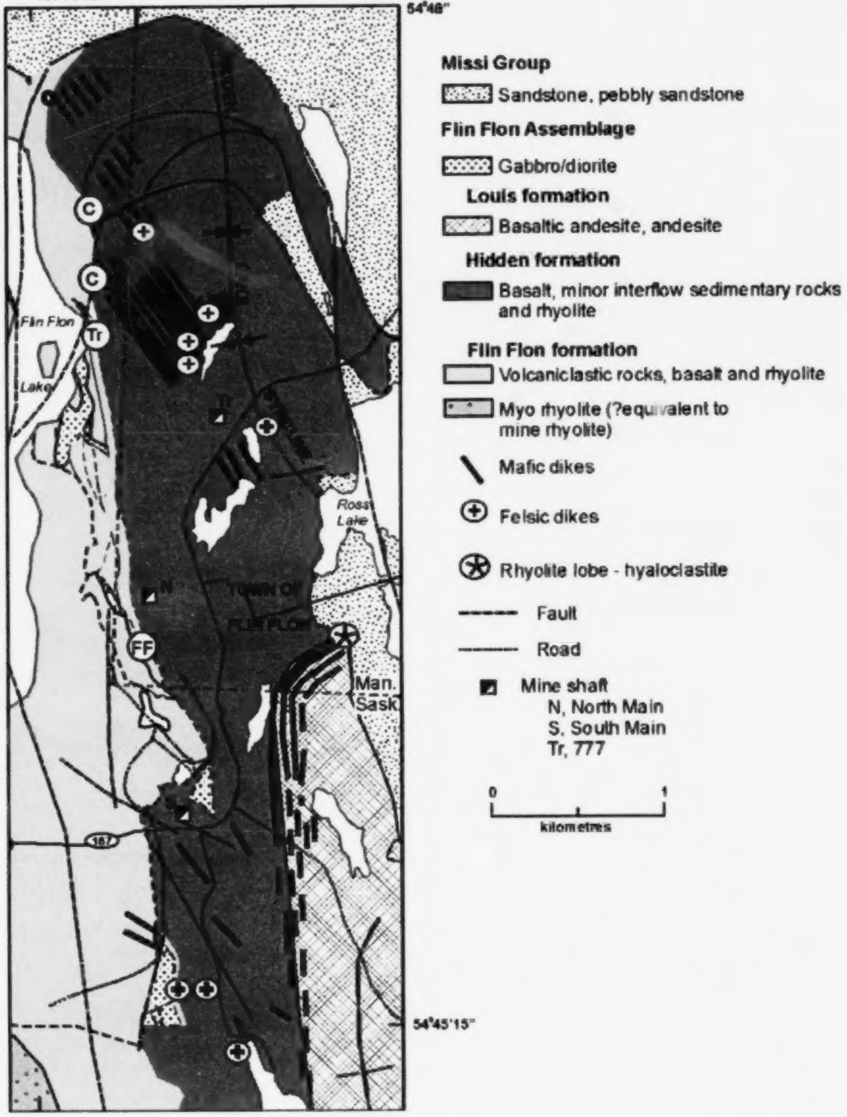

101°53'30"
101°51'30"
54°48"
Missi Group
Sandstone, pebbly sandstone
Flin Flon Assemblage
Gabbro/diorite
Louis formation
Basaltic andesite, andesite
Hidden formation
Basalt, minor interflow sedimentary rocks and rhyolite
Flin Flon formation
Volcaniclastic rocks, basalt and rhyolite
Myo rhyolite (?equivalent to mine rhyolite)
Mafic dikes
Felsic dikes
Rhyolite lobe - hyaloclastite
Fault
Road
Mine shaft
N, North Main
S, South Main
Tr, 777
0
1
kilometres
C
C
Tr
Flin Flon
Lake
Tr
S
Ross
Lake
N
TOWN OF
FLIN FLON
FF
Man.
Sask
167
54°45'15"

Figure GS-2-3: Distribution of mafic dike swarms, felsic dikes and the Tower member felsic lobe-hyaloclastite flow at the top of the Hidden formation. See Figure GS-2-1 for location of traverse areas.

777 section

The central 777 area extends from the northern limit of the town of Flin Flon to the Railway Fault (Fig. GS-2-1). The stratigraphic sequence exposed in this area is bounded by the Flin Flon formation at its base and terminated 650 m above this by the Hidden Lake syncline (Fig. GS-2-1). Detailed mapping of an area up-plunge from the 777 VMS deposit (Tardif, work in progress; Galley and Bailes, 2001) defined approximately seven basaltic andesite flows crosscut by a series of mafic dikes and subordinate felsic dikes that strike 145° (Fig. GS-2-4, Table GS-2-1). This section is dominated by amygdaloidal, plagioclase- and/or pyroxene-phyric flows and minor aphyric flows with associated flow-top breccia. The flows vary from 15 to 430 m thick and are dominantly pillowed, with pillows ranging in size from 0.1 to 10 m (Table GS-2-1). Contacts between flows are sharp and irregular, with some flows showing an irregular transition from pillowed to amoeboid-shaped pillow breccia.

Within interpillow areas, three different textures are observed: 1) thinly bedded to laminated clastic sedimentary

Table GS-2-1: Description of flow units in the Hidden formation, 777 section (N. Tardif, M.Sc. in progress).

Flows		Field description	Mineralogy , volcanic textures/structures	Alteration mineralogy, textures	Contacts
Flow 6 (~10-20 m)	Epidotized, aphyric, mega-pillowed andesite	Medium, densely packed pillows (1% mafic mineral (pyroxene replacing albite?), 1-10% quartz amygdules increasing at pillow margins); minor epidote-altered interpillow sedimentary rocks; 1-2% epidote patches at pillow margins; trace pyrite in interpillow selvages	Fine-grained matrix (high albite microlites (25-30%), hyalopelitic, minor quartz, actiniolite); trace-1% sulphides associated with amygdules; 5% quartz amygdules	Fine-grained actinolite (30%) - epidote (25%), trace pyrite; finely disseminated to coarse grained epidote; epidote greater at margins of amygdules	Irregular and sharp with flow 5
Flow 5E (~60 m)	Epidotized, aphyric, pillowed andesite	Medium to large, densely packed pillows/ tubes (up to 4 m); minor epidote-altered interpillow sedimentary rocks; minor epidote patches (1-2%) at pillow margins, ±pyrite at interpillow selvages	Fine-grained matrix (high albite microlites (25-30%), pilotaxitic, minor quartz, actinolite); 5% quartz amygdules	Very fine grained, pervasive actinolite (25%) - epidote (25-50%); epidote greater at margins of amygdales	Irregular and sharp with flow 5
Flow 5A-D (~430 m)	Feldspar-phyric, amygdular, pillowed andesite	Medium to very large, densely packed pillows/tubes (up to 6 m), concentrically flow banded; plagioclase (10%), pyroxene (2%), chlorite (1-3%); pillows decrease in size near top of flow into a matrix-controlled, amoeboid-shaped breccia; strong epidote-actinolite in smaller pillows and at pillow selvages ±sulphides; 30% quartz-feldspar amygdules; moderately epidote-altered and minor cherty interpillow sedimentary rocks, thinly laminated to finely bedded and interpillow breccia; epidote patches abundant in lower part of flow, in interstitial selvages of breccia and replacing breccia fragments	Fine-grained matrix (±albite microlites (20-30%), hyalopelitic to pilotaxitic, quartz, biotite, ±carbonate); 10-30% quartz-epidote-feldspar-chlorite amygdules; 10% medium to large albite porphyroclasts; albite content decreases with increasing epidote-actinolite-pyrite alteration (patches/gossan)	Fine-grained matrix, medium to high epidote (25-60%) strongly associated with quartz amygdules; trace pyrite, ± minor actinolite (0-30%) and chorite (0-10%)	Irregular and gradational into amoeboid-shaped breccia; sharp with sill; sharp and irregular with flows 6 and 7
Flow 4 (~30 m)	Patchy epidote-aphyric pillowed andesite	Medium to very large, densely packed aphyric pillows/tubes (up to 10 m) concentrically flow-banded and amoeboid-shaped breccia; pillows decrease in size near top of flow into a matrix-controlled amoeboid breccia to the northwest (~10 m); quartz/feldspar amygdules (5%); moderately epidote-altered interpillow sedimentary rocks, ±pyrite-chlorite-chert, thinly laminated to finely bedded, injecting into tubes/pillows; minor interpillow breccia; alteration increases at pillow margins, ±pyrite-chlorite; moderate epidote patches in tube cores	Fine-grained matrix (high albite microlites (30-35%), hyalopelitic, minor quartz, actinolite, biotite); 1-2% quartz amygdules ± carbonate; quartz/albite porphyroclasts (4%); albite decreases with increasing epidote-actinolite-pyrite alteration (patches)	Moderately clotty and pervasive epidote (25-35%) - actinolite(15-25%) - chlorite (20-25%) alteration, fine grained in matrix	Irregular and gradational into amoeboid-shaped breccia, sharp with flow 5

Table GS-2-1: Description of flow units in the Hidden formation, 777 section (N. Tardif, M.Sc. in progress). (continued)

Flows		Field description	Mineralogy , volcanic textures/structures	Alteration mineralogy, textures	Contacts
Flow 3 (~80 m)	Aphyric pillowed andesite	Medium, densely packed, concentrically flow-banded pillows; minor to moderately epidote-altered, thinly laminated to finely bedded interpillow sedimentary rocks (± moderate chert) and minor interpillow breccia (15-40%); plagioclase (7%), pyroxene (3%), quartz-feldspar amygdules (10-15%); 2-10 cm epidote-altered, amoeboid-shaped fragments ±pyrite in matrix; moderate to strong epidote patches in pillow cores and amoeboid-shaped breccia ±chlorite at margins; fracture-controlled epidote; 3-20 m interflow sediment near top of flow, between flows 3A and 3B	Fine-grained matrix (microlites, hyalopelitic and minor pilotaxitic albite (10-20%) ± actinolite, pyroxene, biotite, low quartz); 1% quartz amygdules ± carbonate; albite content decreases with increasing epidote-actinolite-pyrite alteration (patches)	Moderate to strong pervasive epidote (35-60%); moderate actinolite (30%) - chlorite(10-15%); trace pyrite	Gradational into amoeboid-shaped pillow breccia, sharp with flow 4; pillows flattened near sharp contact with dikes
Flow 2 (~25 m)	Pyroxene-phyric pillowed andesite	Medium, densely packed pillows (10% pyroxene and 10% quartz + minor feldspar amygdules) with minor, thinly laminated, epidote-altered interpilllow sedimentary rocks (minor chert) and minor interpillow breccia	Strongly altered, fine- to medium-grained matrix; very low albite (1%), moderate pyroxene (5-10%), actinolite porphyroclasts (5%); 15% quartz amygdules surrounded by actinolite-chlorite-epidote halos	Strong, finely disseminated epidotization; moderate development of acicular, fine-grained actinolite; minor fine-grained chlorite in matrix	Sharp, irregular with flow 3
Flow 1 (~15 m)	Feldspar-phyric pillowed andesite	Medium, densely packed pillows (1% pyroxene, 1% feldspar, 1% quartz-feldspar amygdules); minor, thinly laminated, epidote-altered interpilllow sedimentary rocks; minor fracture-controlled epidote veins; generally, alteration is pervasive and fracture-controlled, ghostly at pillow cores and near margins of dikes	Fine-grained matrix (quartz±actinolite±pyroxene, no albite microlites) 10% quartz amygdules and albite porphyroclasts (8%)	Strong actinolite (30-35%), moderate chlorite (15%), epidote (15%) in matrix	Sharp, sheared with flow 2

rocks with bedding planes parallel to pillow selvages; 2) interpillow chert; and 3) interpillow hyaloclastite. Peperitic textures within interpillow and interflow mafic sedimentary strata are locally observed. Discontinuous units of mafic sedimentary rocks occur in the basal 120 m of the Hidden Lake sequence, between the massive gabbro flow and flow 1, and between flows 3 and 4 (Fig. GS-2-4).

The central 777 deposit area is transected by a mafic dike swarm trending 145°, perpendicular to the stratigraphy (Fig. GS-2-3). Mafic dikes are of andesitic composition and vary from aphyric to feldspar- and pyroxene-phyric. Felsic dikes of rhyolitic composition are also concentrated in this zone and are generally crosscut by the mafic dikes.

Flin Flon section

The lower approximately 100 m of the Hidden formation in the Flin Flon to South Main section contains 10 to 15 m thick units of aphyric and minor feldspar-phyric basalt containing gas cavities, along with beds of scoriaceous, amoeboid breccia and peperite. The overall 500 m thick sequence changes upsection from basaltic flows and pyroclastic rocks to alternating lobe-hyaloclastite and closely packed pillows, characterized by pipe vesicles and concentric cooling cracks. This mafic flow facies is overlain by rhyolite of the Tower member at the top of the Hidden formation. The Tower member consists of aphyric to sparsely quartz-phyric, lobe-hyaloclastite rhyolite flows with

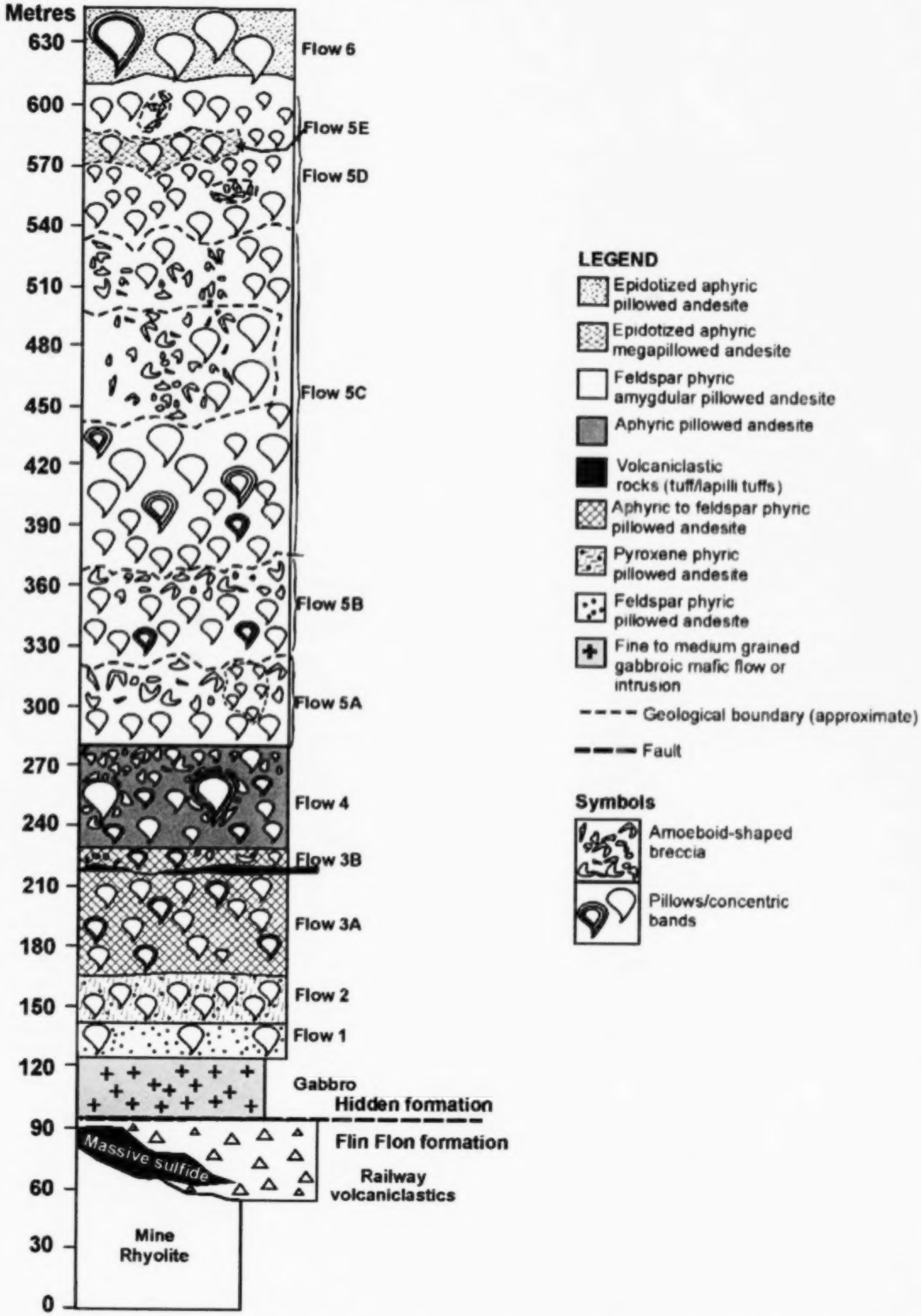

Metres
630
600
570
540
510
480
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
0
Flow 6
Flow 5E
Flow 5D
Flow 5C
Flow 5B
Flow 5A
Flow 4
Flow 3B
Flow 3A
Flow 2
Flow 1
Gabbro
Hidden formation
Flin Flon formation
Massive sulfide
Railway volcaniclastics
Mine Rhyolite
LEGEND
Epidotized aphyric pillowed andesite
Epidotized aphyric megapillowed andesite
Feldspar phyric amygdular pillowed andesite
Aphyric pillowed andesite
Volcaniclastic rocks (tuff/lapilli tuffs)
Aphyric to feldspar phyric pillowed andesite
Pyroxene phyric pillowed andesite
Feldspar phyric pillowed andesite
Fine to medium grained gabbroic mafic flow or intrusion
Geological boundary (approximate)
Fault
Symbols
Amoeboid-shaped breccia
Pillows/concentric bands

Figure GS-2-4: Stratigraphic section through the Hidden formation above the 777 VMS deposit, based on 1:1000-scale mapping by Tardif (see Figure GS-2-1 for location).

felsic volcaniclastic talus and distal sulphidic mafic siltstone. The hydrothermal alteration overprint on the volcanic sequence also differs from other sections (Fig. GS-2-5, GS-2-6, GS-2-7).

Phantom Lake section

The Millrock Hill to Phantom Lake section in the south is strongly sheared at its base due to the presence of a subsequently deformed early thrust-fault system (Galley et al., 2001). The lowermost 115 m contain mafic tuffaceous rock as interpillow material, accompanied by up to 60 m thick zones of globular peperite. The principal tuffaceous interflow units occur at 70, 200, 230 and 255 m above the base of the formation. The mafic tuff layers are strongly sheared, and may contain accretionary lapilli, graded bedding, quartz-phyric rhyolite fragments and minor scoria. Basaltic andesite flows vary between 5 and 60 m in thickness, and are generally aphyric to sparsely feldspar- and/or pyroxene-phyric. Pillow morphology varies from megapillows (>12 m) to rounded equant pillows (approx. 50–70 cm) and very minor amoeboid breccia. The upper 120 m of pillowed basalt contain concentric cooling cracks, radial pipe vesicles and scoriaceous, amoeboid breccia. Flow indicators suggest a southward flow direction for the flows in this section. The top of the section is characterized by a thin (<1 m) bed of mafic sediment of the Tower member, overlain by the feldspar-pyroxene–phyric basalt of the Louis formation.

Myo Lake section

A section through the western, southwest-younging limb of the Beaver Road anticline (Stockwell, 1960) was mapped at a scale of 1:2000 (Fig. GS-2-1). The base of the 'hanging wall' section, described herein, is marked by a slightly sheared contact with the top of the Myo rhyolite. At this locality, on the east side of Myo Lake, the rhyolite (unit 1, Fig. GS-2-8) is sparsely quartz and plagioclase phyric and massive. Within this section, there is a relatively high degree of strain and some transposition of units into the main, southeast-striking, steeply (60–80°) southwest-dipping foliation. Considering the overall degree of flattening, thicknesses have not been corrected for dip and are therefore apparent thickness only (Fig. GS-2-8). The section is just less than 1500 m thick, including covered sections between outcrops and the 50% intrusive material.

Five different types of volcanic rocks are distinguished, based on their field characteristics (unit numbers correspond to those on Fig. GS-2-8):

1) unit 2: dark brown weathering, aphyric, sparsely to nonamygdular (quartz+plagioclase–filled, <5%, 5–25 mm diameter), pillowed flows, the pillows typically of relatively large size (75–200 cm) with irregular shapes, concentric cooling fractures, pipe vesicles near the margins, thin rims and patchy epidotization
2) unit 3: light greenish brown to yellowish brown weathering, aphyric, strongly amygdular (quartz+plagioclase–filled, 10–30%, 1–50 mm diameter), pillowed flows, the pillows commonly of small to medium size (30–150 cm) with pervasive epidotization and silicification
3) unit 4: light to medium greenish brown weathering, aphanitic to fine-grained, sparsely to moderately amygdular (quartz+plagioclase±mafic–filled, 2–10%, 5–15 mm diameter), massive flows, typically with large (3–10 cm) quartz- and epidote-filled gas cavities and epidosite patches
4) unit 5: light greenish grey weathering, sparsely (<2%, <5 mm) to moderately (5–10%, 3–8 mm) plagioclase±pyroxene-phyric, non- to sparsely amygdular (<2%), massive to pillowed flows, with patchy epidotization
5) unit 6: aphyric to sparsely quartz- and plagioclase-phyric (<2%, <4 mm), massive to fragmental rhyolite (may be partly intrusive and/or resedimented volcaniclastic rocks).

Close to 50% of this section consists of intrusive material, most of which has a sill-like orientation. Because of deformation, however, it is difficult to determine if this is primary or partially a result of transposition. Based on field characteristics, seven different groups of intrusive rocks have been distinguished (unit numbers correspond to those on Fig. GS-2-8):

1) unit 8: fine-grained to aphanitic, aphyric, light greenish brown weathering, sparsely to moderately amygdular (quartz+plagioclase±mafic, < 5%) dikes and sills, commonly with large (3–10 cm) epidote- and quartz-filled gas cavities and epidosite patches
2) unit 9: light greenish grey–weathering, plagioclase- and pyroxene-phyric (5–15%, 5–12 mm), nonamygdular dikes and sills
3) unit 10: fine- to medium-grained, aphyric to sparsely plagioclase-phyric (<2%, <8 mm), equigranular gabbro
4) unit 11: aphyric, fine-grained to aphanitic, nonamygdular, reddish brown weathering, mafic dikes, commonly with flow banding

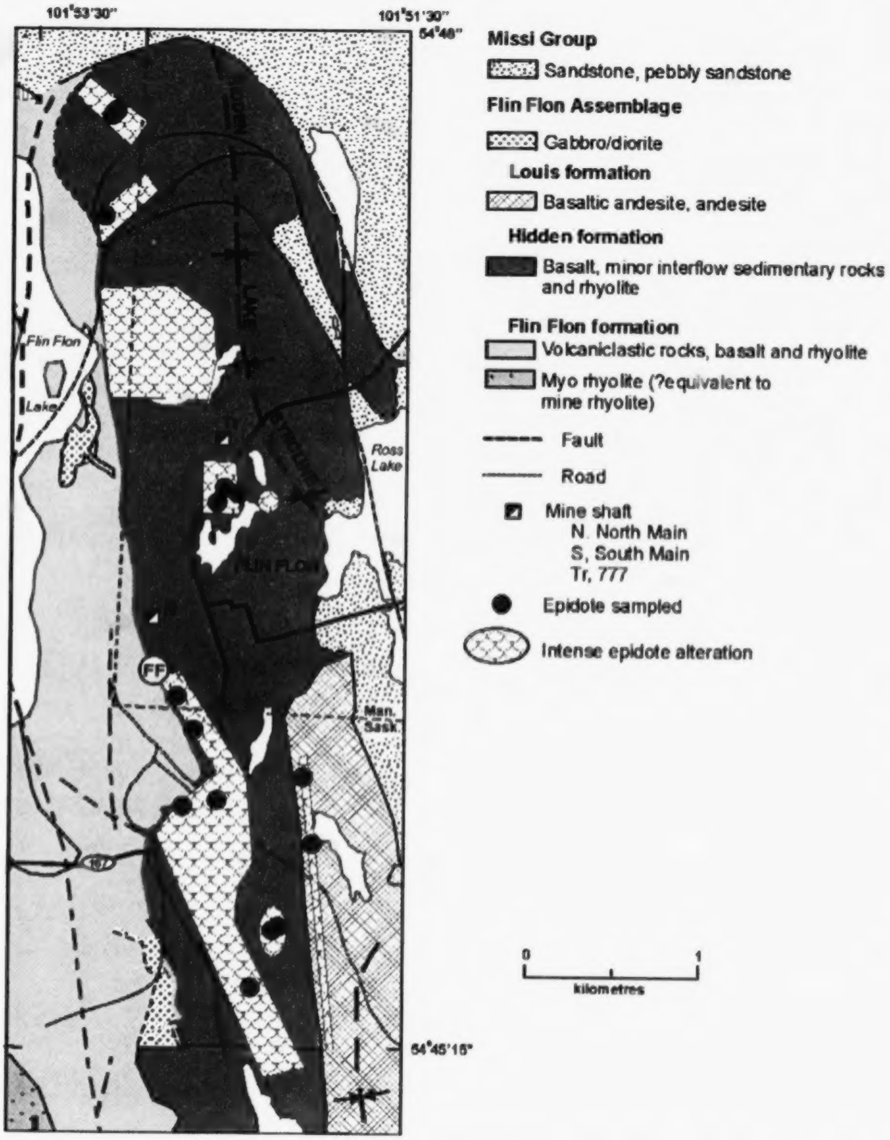

101°53'30"
101°51'30"
54°48"
54°45'15"
Flin Flon
Lake
Ross
Lake
FLIN FLON
FF
Man.
Sask.
167
Missi Group
Sandstone, pebbly sandstone
Flin Flon Assemblage
Gabbro/diorite
Louis formation
Basaltic andesite, andesite
Hidden formation
Basalt, minor interflow sedimentary rocks and rhyolite
Flin Flon formation
Volcaniclastic rocks, basalt and rhyolite
Myo rhyolite (?equivalent to mine rhyolite)
Fault
Road
Mine shaft
N, North Main
S, South Main
Tr, 777
Epidote sampled
Intense epidote alteration
0
1
kilometres

Figure GS-2-5: Distribution of epidote alteration in the hanging wall Hidden and Louis formations, as defined through mapping in this study. See Figure GS-2-1 for location of traverse areas.

5) unit 12: medium- to coarse-grained leucogabbro, locally with pegmatitic patches

6) unit 13: aphyric, aphanitic, nonamygdular, blue-grey–weathering, mafic to intermediate dikes

7) unit 14: light greenish brown, fine-grained, sparsely plagioclase-phyric (<2%, <5 mm) intermediate dikes

Where contact relationships are not observed or are significantly strained, it is difficult to distinguish between intrusive rocks of unit 8 and volcanic rocks of unit 4; a volcanic origin has been assumed in such cases.

This section also contains a variety of sedimentary rocks, including thinly bedded to laminated chert and cherty argillite (unit 7) that may be interbedded with thinly bedded mafic tuff and lapilli tuff, locally with felsic fragments (unit 7a), or with thinly to moderately bedded, normally graded, mafic greywacke (unit 7b).

Both the strongly amygdular (unit 3) and the nonamygdular (unit 2) flows occur throughout the section, although the proportion of sparsely to nonamygdular flows decreases toward the top of the section. Massive flows are also more common near the base of the section, whereas the top is dominated by pillowed flows and amoeboid pillow breccia.

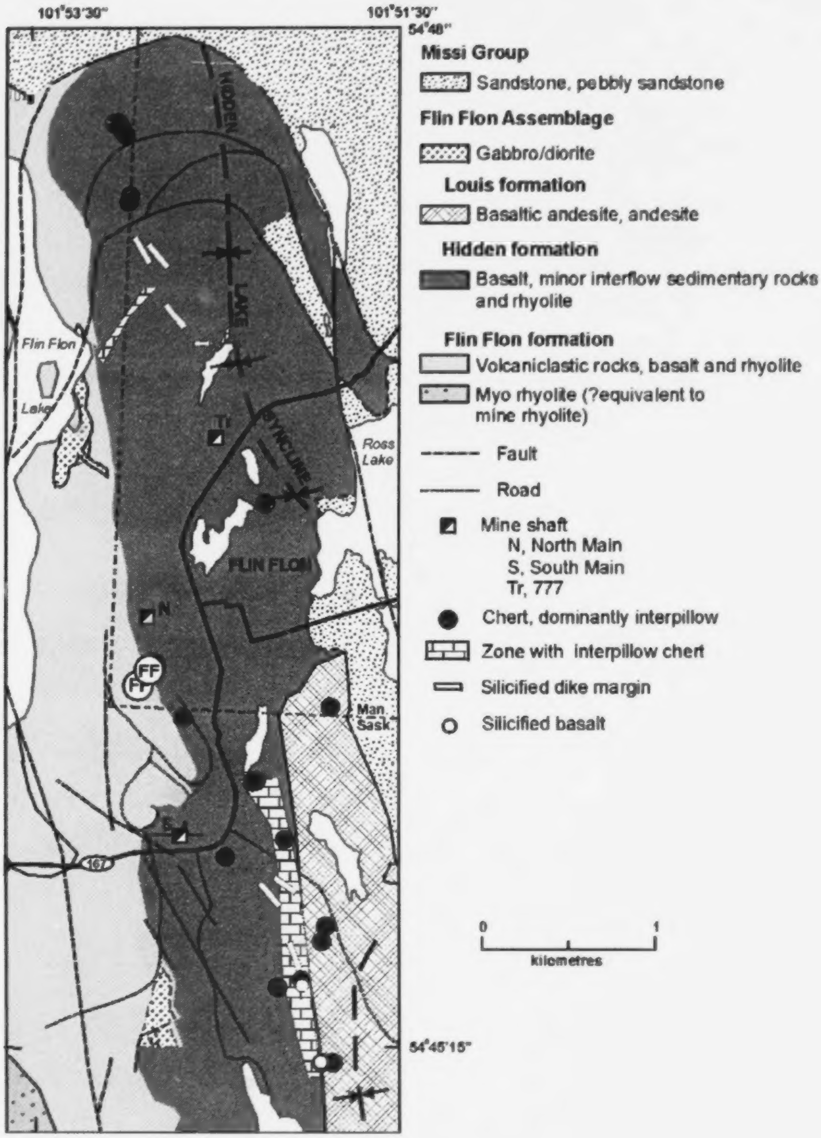

101°53'30"
101°51'30"
54°48"
54°45'15"
Missi Group
Sandstone, pebbly sandstone
Flin Flon Assemblage
Gabbro/diorite
Louis formation
Basaltic andesite, andesite
Hidden formation
Basalt, minor interflow sedimentary rocks and rhyolite
Flin Flon formation
Volcaniclastic rocks, basalt and rhyolite
Myo rhyolite (?equivalent to mine rhyolite)
Fault
Road
Mine shaft
N, North Main
S, South Main
Tr, 777
Chert, dominantly interpillow
Zone with interpillow chert
Silicified dike margin
Silicified basalt
0
1
kilometres
HIDDEN
LAKE
SYNCLINE
FLIN FLON
Flin Flon
Lake
Ross
Lake
Man.
Sask.
167
N
S
Tr
FF
FT

Figure GS-2-6: Distribution of interpillow chert and silicification in the hanging wall Hidden and Louis formations, as defined through mapping in this study. See Figure GS-2-1 for location of traverse areas.

Plagioclase- and pyroxene-phyric flows are rare and were only observed in one outcrop near the base of the section. However, the occurrence of similar dikes throughout the section suggests that the magma source for these flows was still active and may have been feeding flows higher in the sequence. Cherty horizons occur throughout the sequence, although they are most prevalent at the base and rare at the top. Accretionary lapilli within mafic tuff horizons indicate a subaerial eruption column and relatively shallow water deposition for at least part of the succession. Mafic dikes and sills are common throughout the section, are texturally and compositionally similar to the volcanic rocks, and are inferred to be synvolcanic. In some cases, textural relationships such as peperitic margins and irregularly fractured tops with chert infill suggest that sills have intruded into unlithified sediments. A horizon of amoeboid, mixed mafic volcanic rocks and chert at the top of the lowermost pillowed flow suggests that the pillows flowed into unlithified cherty sediments that were deposited prior to the initiation of this sequence of mafic volcanism.

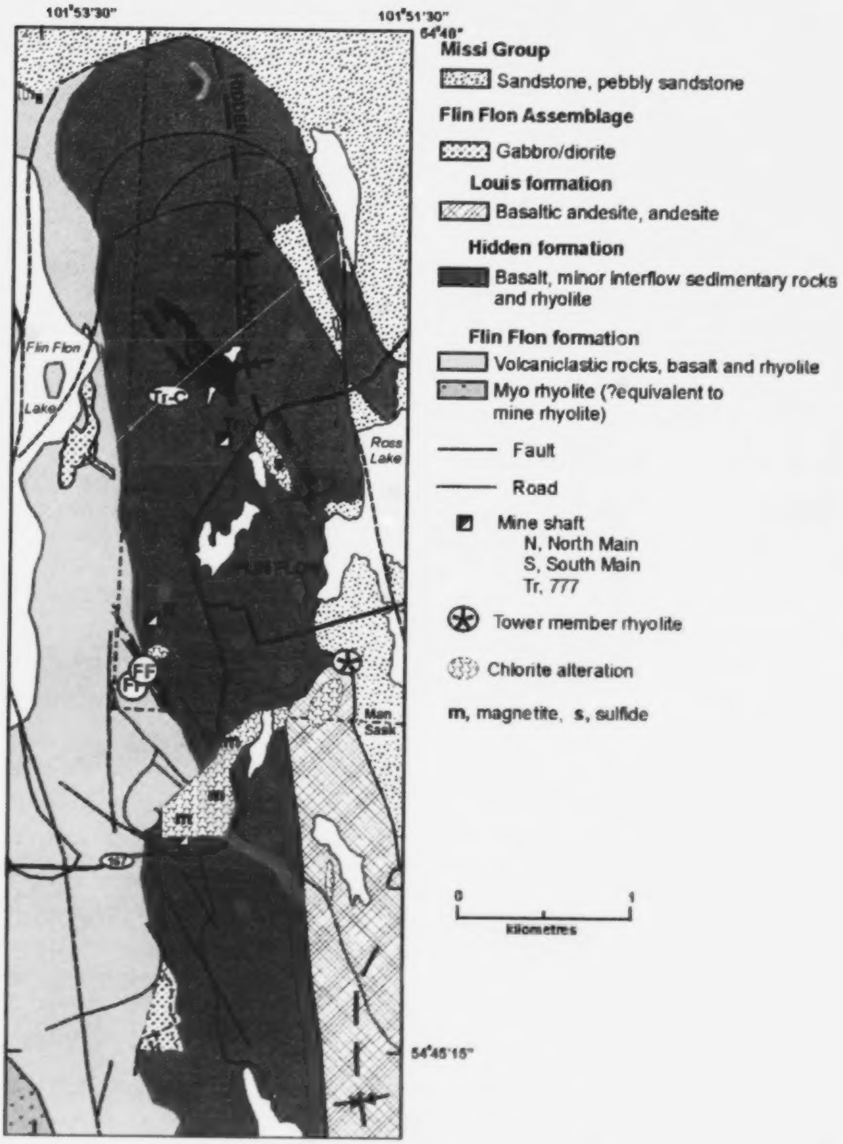

101°53'30"
101°51'30"
54°48'
54°46'15"
Missi Group
Sandstone, pebbly sandstone
Flin Flon Assemblage
Gabbro/diorite
Louis formation
Basaltic andesite, andesite
Hidden formation
Basalt, minor interflow sedimentary rocks and rhyolite
Flin Flon formation
Volcaniclastic rocks, basalt and rhyolite
Myo rhyolite (?equivalent to mine rhyolite)
Fault
Road
Mine shaft
N, North Main
S, South Main
Tr, 777
Tower member rhyolite
Chlorite alteration
m, magnetite, s, sulfide
Flin Flon Lake
Ross Lake
Tr-C
FF
Man Sask
m
167
0
1
kilometres

Figure GS-2-7: Distribution of chlorite in the hanging wall Hidden and Louis formations, as defined through mapping in this study. See Figure GS-2-1 for location of traverse areas.

Louis formation

The lower part of the Louis formation was mapped in this study where it overlies the mafic sedimentary rocks and rhyolite of the Tower member (Hidden formation). The Louis formation contains feldspar-pyroxene–phyric basaltic flows and sills, and minor aphyric pillowed basalt, scoriaceous amoeboid breccia and scoriaceous lapilli tuff. Globular peperite is common in the lower Louis basalt, with sediment as interpillow material extending up to 80 to 120 m above the Hidden-Louis contact. Plagioclase-phyric (15%) and pyroxene-phyric (amphibole pseudomorphs after clinopyroxene, 15%) pillowed flows vary from 10 to 30 m in thickness, with rounded pillows 1 to 1.5 m in size that contain 5 to 10% vesicles.

The Louis formation contains a gabbroic dike swarm (Fig. GS-2-3) with three to six dikes displacing the sedimentary rocks and rhyolite of the Tower member. The gabbroic dikes are massive to columnar jointed, 15 to 40 m wide and contain vesicles that may be concentrated in linear zones along the top of each dike.

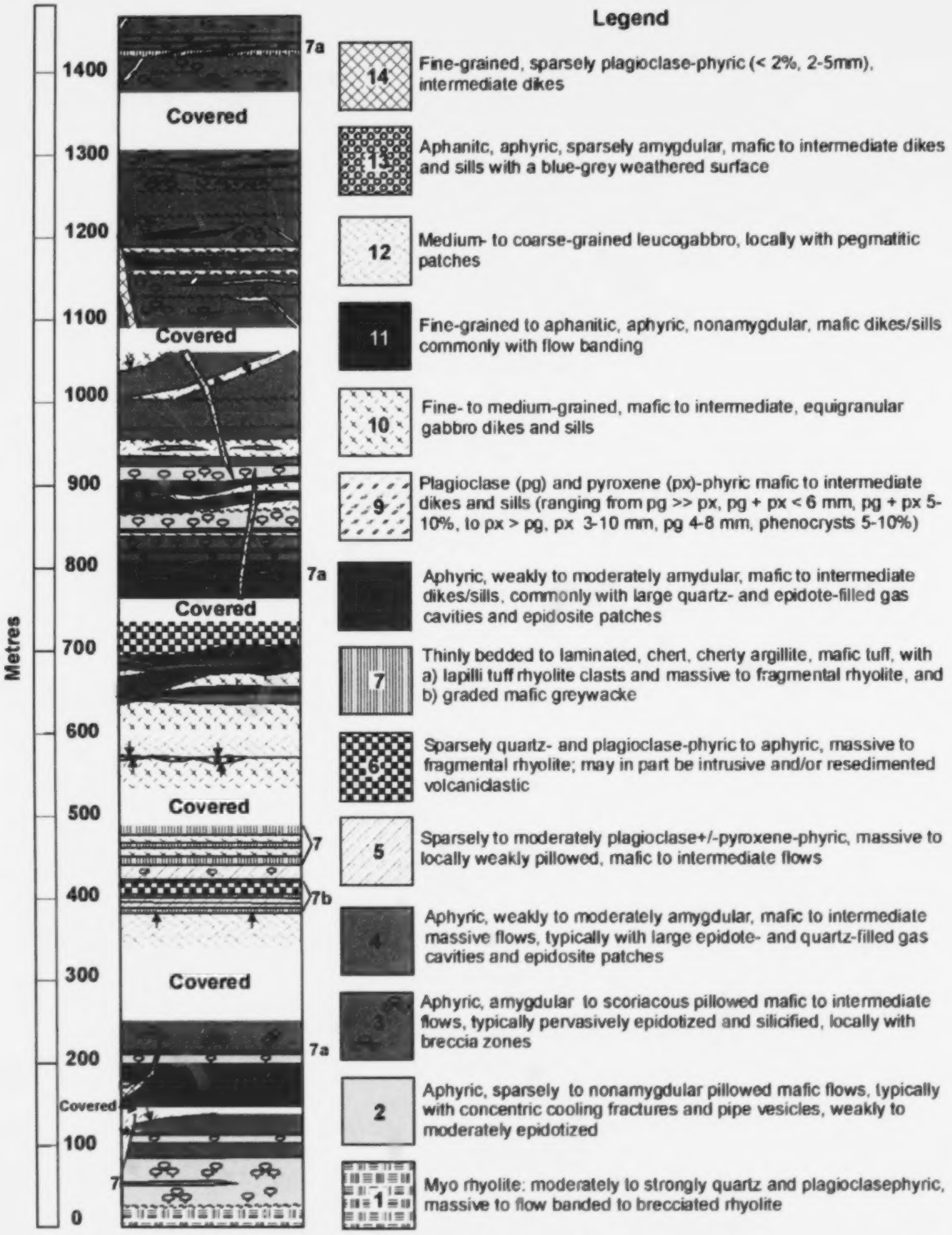

Metres
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Covered
Covered
Covered
Covered
Covered
Covered
7a
7a
7
7b
7a
7
Legend
14 Fine-grained, sparsely plagioclase-phyric (< 2%, 2-5mm), intermediate dikes
13 Aphanitc, aphyric, sparsely amygdular, mafic to intermediate dikes and sills with a blue-grey weathered surface
12 Medium- to coarse-grained leucogabbro, locally with pegmatitic patches
11 Fine-grained to aphanitic, aphyric, nonamygdular, mafic dikes/sills commonly with flow banding
10 Fine- to medium-grained, mafic to intermediate, equigranular gabbro dikes and sills
9 Plagioclase (pg) and pyroxene (px)-phyric mafic to intermediate dikes and sills (ranging from pg >> px, pg + px < 6 mm, pg + px 5-10%, to px > pg, px 3-10 mm, pg 4-8 mm, phenocrysts 5-10%)
8 Aphyric, weakly to moderately amydular, mafic to intermediate dikes/sills, commonly with large quartz- and epidote-filled gas cavities and epidosite patches
7 Thinly bedded to laminated, chert, cherty argillite, mafic tuff, with a) lapilli tuff rhyolite clasts and massive to fragmental rhyolite, and b) graded mafic greywacke
6 Sparsely quartz- and plagioclase-phyric to aphyric, massive to fragmental rhyolite; may in part be intrusive and/or resedimented volcaniclastic
5 Sparsely to moderately plagioclase+/-pyroxene-phyric, massive to locally weakly pillowed, mafic to intermediate flows
4 Aphyric, weakly to moderately amygdular, mafic to intermediate massive flows, typically with large epidote- and quartz-filled gas cavities and epidosite patches
3 Aphyric, amygdular to scoriacous pillowed mafic to intermediate flows, typically pervasively epidotized and silicified, locally with breccia zones
2 Aphyric, sparsely to nonamygdular pillowed mafic flows, typically with concentric cooling fractures and pipe vesicles, weakly to moderately epidotized
1 Myo rhyolite: moderately to strongly quartz and plagioclasephyric, massive to flow banded to brecciated rhyolite

Figure GS-2-8: Stratigraphic section through the Hidden formation–equivalent above the Myo rhyolite (see Fig. GS-2-1). Chilled margins are indicated by arrows within the various intrusions. The thickness of the thinnest units depicted may be exaggerated for clarity.

HANGING WALL ALTERATION IN THE FLIN FLON–777–CALLINAN VMS HORIZON

Hydrothermal alteration in the Hidden and Louis formations comprises the following types: epidote-quartz alteration, silicification, chloritization, feldspar-quartz alteration and sulphide mineralization. A pervasive middle greenschist facies metamorphic assemblage, consisting of actinolite-epidote-albite-quartz ±biotite, characterizes regional metamorphism in the Flin Flon area (Bailes and Syme, 1989).

Epidote-quartz alteration was mapped as textural types (i.e., coarse grained, fine granular with diffuse boundaries, replacement interpillow material, cores of pillows, along columnar joints, concentrated around amygdules, pervasive, patchy, ribbons, fractures) to define the paragenesis, distribution and controls on alteration. Epidote-quartz alteration is most intense in the lower two-thirds of the Hidden formation (Fig. GS-2-5).

Silicification is not an abundant alteration type in the Flin Flon camp. In the southern segment of the Louis dike swarm, there is minor silicification of pillows (Fig. GS-2-6). Silicification (quartz>>epidote) is locally concentrated along dike margins in both of the dike swarms. 'Chert' commonly replaces interpillow sediment and occurs 1) at the base of the Hidden and Louis formations, and 2) in the upper 120 m of the Hidden formation (Fig. GS-2-6). Quartz is common as a vesicle filling.

Chlorite alteration is concentrated 1) in a chlorite-magnetite discordant zone above the Flin Flon main deposit towards rhyolite of the Tower member (Hidden formation) and extending into the Louis formation; and 2) associated with gossans near the top of the Hidden formation in the trend of the felsic dikes (Fig. GS-2-7). The chlorite alteration zone above the Flin Flon main deposit also contains anomalous sulphide mineralization. Chlorite occurs in the matrix and pillow selvages, and fills amygdules.

Sulphidic zones in the hanging wall basalt were found to be associated with the chlorite alteration described above, in sedimentary rocks near the base of the Hidden formation, and in the rhyolite and associated sediment at the top of the Hidden formation.

FUTURE STUDIES

Geochemical classification of the volcanic rocks of the Hidden formation, the Louis formation and the Myo section is in progress on approximately 120 basalt, rhyolite and dike samples. Interflow and interpillow sediment was sampled for geochemistry, petrography and x-ray diffraction, to identify the nature and composition of the detrital and hydrothermal components. Definition of the compositions of the orebodies (Jonasson et al., GS-4, this volume) and the sediment alteration will test the validity of a hydrothermal plume above the Flin Flon–777–Callinan mine horizon. Core logging and sampling of interpillow material from four drillholes through the Hidden formation in 2002 provides a depth component to the hanging wall plume study. In total, close to 400 samples of the hanging wall strata and alteration were submitted for analysis, including 230 sediment samples, 20 chert samples, 78 volcanic samples, 12 dike samples and 20 epidote-altered basalt samples.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Manitoba Geological Survey for their logistical support throughout the two field seasons of this project, and Hudson's Bay Exploration and Development Co. Ltd., particularly Tom Lewis, Kelly Gilmore and Edgar Wright, for supplying the digital, orthorectified airphoto coverage in and around the town of Flin Flon and for their continuous advice and support. The authors would also like to thank Hudson's Bay Mining and Smelting Co Ltd. for permission to work on their property.

REFERENCES

Bailes, A.H. and Syme, E.C. 1989: Geology of the Flin Flon–White Lake area; Manitoba Energy and Mines, Minerals Division, Geological Report GR87-1, 313 p.

Franklin, J.M., Lydon, J.W. and Sangster, D.f. 1981: Volcanic-associated massive sulfide deposits; Economic Geology, 75th Anniversary Volume, p. 485–627.

Galley, A.G. and Bailes, A.H. 2001: Flin Flon Targeted Geoscience Initiative; *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geolgical Survey, p. 9–17.

Galley, A., Bailes, A., Gibson, H., Tourigny, G., Ames, D., Devine, C., Gale, G., Jonasson, I., Mitchinso, D., Syme, E., Tardif, N. and Taylor, B. 2001: Preliminary results from the Flin Flon Targeted Geoscience Initiative, Saskatchwan and Manitoba; Geological Survey of Canada, Current Research, 2001-C24, p. 1–11.

Gibson, H.L. and Watkinson, D.H. 1990: Volcanogenic massive sulphide deposits of the Noranda cauldron and shield volcano, Quebec; *in* The Northwestern Quebec Polymetallic Belt, P.V.M. Rive, Y. Gagnon, J.M. Lulin, G. Riverin and A. Simard (ed.), Canadian Institue of Mining and Metallurgy, Special Volume 43, p. 119–132.

Riverin, G., LaBrie, M., Salmon, B., Cazavant, A., Asselin, R. and Gagnon, M. 1990: The geology of the Ansil deposit, Rouyn-Noranda, Quebec; *in* The Northwestern Quebec Polymetallic Belt, P.V.M. Rive, Y. Gagnon, J.M. Lulin, G. Riverin and A. Simard (ed.), Canadian Institute of Mining and Metallurgy, Special Volume 43, p. 143–152.

Stockwell, C.H. 1960: Flin Flon–Mandy Lake area, Manitoba and Saskatchewan; Geological Survey of Canada, Map 17078A, 1:12 000 scale, with descriptive notes.

Syme, E.C. and Bailes, A.H. 1993: Stratigraphy and tectonic setting of Early Proterozoic volcanogenic massive sulphide deposits, Flin Flon, Manitoba; Economic Geology, v. 88, p. 566–589.

Thomas, D.J. 1990: Bedrock geology, Douglas-Phantom Lakes area (parts of NTS 63K-12, -13); 1:12 500 scale map accompanying Summary of Investigations 1990, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 90-4.

GS-3 ALTERATION OF THE PALEOPROTEROZOIC FELSIC VOLCANIC BAKER PATTON COMPLEX (NTS 63K12NE AND 13SE), FLIN FLON, MANITOBA

by D.E. Mitchinson[1], H.L. Gibson[1] and A.G. Galley[2]

Mitchinson, D.E., Gibson, H.L. and Galley, A.G. 2002: Alteration of the Paleoproterozoic felsic volcanic Baker Patton Complex (NTS 63K12NE and 13SE), Flin Flon, Manitoba; *in* Report of Activities, 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 35-40.

INTRODUCTION

Studies by Hannington et al. (in press a, b) on the regional-scale hydrothermal systems of the Noranda (Quebec) and Kristineberg (Sweden) VMS districts have demonstrated the importance of using metamorphosed hydrothermal mineral assemblages in detecting centres for robust, subseafloor hydrothermal activity. Furthermore, these studies illustrated the usefulness of the X-ray diffraction method for the efficient identification of key alteration minerals and their semi-quantitative abundances. The felsic Baker Patton Complex is one of three study areas chosen, during the Flin Flon Targeted Geoscience Initiative (FFTGI), in which to further test this detection method, and compare its reliability against petrographic analysis and lithogeochemistry-generated modal mineralogy.

Volcanogenic massive sulphide (VMS) deposits of the Paleoproterozoic Flin Flon Belt of Saskatchewan and Manitoba are commonly associated with rhyolitic flows and volcaniclastic rocks within predominantly mafic terranes (Syme and Bailes, 1993). The dominantly felsic, approximately 50 km^2, Baker Patton Complex (BPC) is the largest domain of felsic rocks in the Flin Flon Belt and has been a target for much VMS exploration activity. Although the BPC does host a number of small, subeconomic VMS deposits and occurrences, and locally displays evidence of having undergone intense hydrothermal alteration, it is inexplicably devoid of significant VMS mineralization.

The BPC has been previously studied by both government (Gale et al., 1992, 1993; Gale and Dabek, 1995, 2002) and industry (Prior and Dabek, 1999) workers. The objective of this study is to evaluate the primary volcanological controls on alteration type and intensity, and to evaluate different methodologies, including lithogeochemistry and mineralogy derived from X-ray diffraction (XRD), with which hydrothermal alteration in the felsic complex can be quantified. This will assist in further evaluation of the VMS potential of the BPC.

This subproject is part of the Flin Flon Targeted Geoscience Initiative (FFTGI), the objective of which is to gain a better understanding of the hydrothermal systems associated with the various VMS deposits and prospects in the Flin Flon region, thereby assisting industry in developing new exploration criteria. The final product of this particular subproject will be an M.Sc. thesis in the form of a published paper. The map-based results are to be published, along with the results of the other FFTGI projects, in a geographic information system (GIS) format on a Geological Survey of Canada (GSC) CD-ROM release in the spring of 2003.

METHODOLOGY

This study is focused on felsic flows of the western half of the BPC, where four subeconomic VMS deposits are located (Fig. GS-3-1). The initial analysis of lithogeochemical data will be followed by an assessment of mineralogical variations derived from semiquantitative XRD analysis of BPC samples using the WinJade XRD software package. The effect of flow morphology on the distribution of alteration, as defined by lithogeochemistry and XRD-derived mineralogy, will also be examined. The effectiveness of each method in defining VMS-related hydrothermal alteration zones related to known deposits will be evaluated at the deposit scale and at the scale of the entire BPC.

REGIONAL GEOLOGY

The Flin Flon Belt (FFB) is a Paleoproterozoic greenstone belt located within the Reindeer Zone of the Trans-Hudson Orogen (*see* inset on Fig. GS-3-1). To the north, the FFB is bounded by the Kisseynew Gneiss Belt and, to the south, it extends beneath Paleozoic rocks of the Western Interior Platform. The FFB is composed of structurally amalgamated arc, ocean-floor and ocean-island volcanic assemblages, related turbidite deposits and rare Archean crustal fragments (Stern et al., 1995).

The study area occurs within the central FFB, an island arc–back arc assemblage that consists of a series of fault-bounded segments formed during collisional tectonics (Lucas et al., 1996). Stratigraphic units, which cannot be

---

[1] Mineral Exploration Research Centre, Department of Earth Sciences, Laurentian University, Sudbury, ON P3E 2C6

[2] Geological Survey of Canada, 601 Booth St., Ottawa, ON K1A 0E8

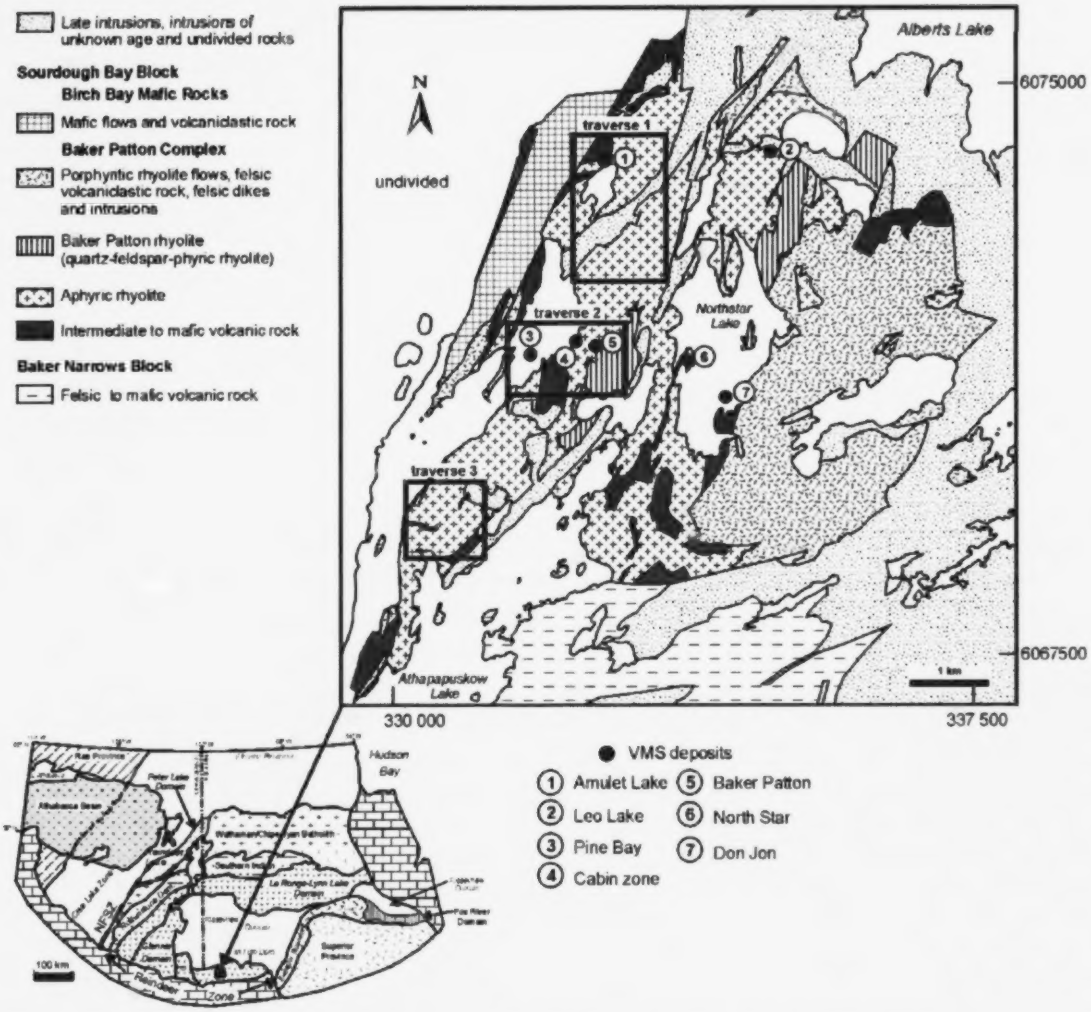

Late intrusions, intrusions of unknown age and undivided rocks
Sourdough Bay Block
Birch Bay Mafic Rocks
Mafic flows and volcaniclastic rock
Baker Patton Complex
Porphyritic rhyolite flows, felsic volcaniclastic rock, felsic dikes and intrusions
Baker Patton rhyolite (quartz-feldspar-phyric rhyolite)
Aphyric rhyolite
Intermediate to mafic volcanic rock
Baker Narrows Block
Felsic to mafic volcanic rock
N
undivided
Alberts Lake
6075000
traverse 1
traverse 2
traverse 3
Northstar Lake
Athapapuskow Lake
1 km
6067500
330 000
337 500
Hudson Bay
100 km
Reindeer Zone
VMS deposits
① Amulet Lake
② Leo Lake
③ Pine Bay
④ Cabin zone
⑤ Baker Patton
⑥ North Star
⑦ Don Jon

Figure GS-3-1: Baker Patton Complex (after Gale and Dabek, 2002), showing VMS deposits and 2001 field season traverse locations. The Baker Patton Complex is located within the Flin Flon Belt of the Trans-Hudson Orogen (inset).

correlated across block-bounding faults, are well preserved and contain mainly greenschist-facies mineral assemblages (Bailes and Syme, 1989; Lucas et al., 1996).

LOCAL GEOLOGY

The BPC (Fig. GS-3-1) is located approximately 16 km east of the town of Flin Flon and lies within the Sourdough Bay Block of the FFB (Bailes and Syme, 1989). The Sourdough Bay Block is the easternmost VMS-hosting structural domain in the Flin Flon arc assemblage and contains the largest volume of felsic volcanic rocks in the FFB.

Due to bounding regional faults and a lack of radiometric dating, the relative stratigraphic position of the BPC within the Flin Flon arc assemblage remains uncertain. The most recent and detailed mapping of the BPC is the work of George Gale and co-workers (Gale et al., 1992, 1993; Gale and Dabek, 1995, 2002). A number of exploration companies have also created detailed property maps of parts of the BPC. Despite this mapping, many of the relationships between units remain unresolved due to lack of outcrop exposure, especially in eastern areas of the BPC (Gale et al., 1993).

The volcanic rocks of the BPC are mainly rhyolite, although rhyodacite and dacite have been delineated using lithogeochemistry; andesite and basalt are volumetrically insignificant. The rhyolite units are generally differentiated by their phenocryst population as either quartz-feldspar–phyric, feldspar-phyric or aphyric. Lobe-breccia–hyaloclastite facies are common throughout most rhyolitic units, and pillows are frequently noted in mafic units. These features suggest a subaqueous environment of deposition for the volcanic rocks (Prior and Dabek, 1999). Units generally trend northeast, parallel to major faults and shear zones. The dip of the units is near vertical as a result of isoclinal folding (Gale and Dabek, 1995). The main foliation parallels major fault zones that are commonly defined by laterally extensive gabbro sills (Prior and Dabek, 1999).

The locations of VMS deposits within the BPC are illustrated in Figure GS-3-1. The largest is the Pine Bay deposit, which has been reported by the Cerro Mining Company of Canada to contain 1 340 000 tonnes at an average grade of 1.5% Cu (Gale and Eccles, 1988).

WORK COMPLETED AND IN PROGRESS

In order to establish the lithostratigraphy, chemostratigraphy, flow facies, alteration types and alteration distribution of the BPC, three traverses, each approximately 300 m wide and mapped at a scale of 1:3500, were conducted in the western portion of the BPC. The stratigraphy in this area is interpreted to be the structurally duplicated equivalent of stratigraphy to the east (Prior and Dabek, 1999). Figure GS-3-2 shows examples of western BPC rock types and flow morphologies, summarized in preliminary maps and accompanying stratigraphic sections for traverses 1 and 2. Representative samples were collected of all rock types, textures, morphologies, alteration types and alteration intensities on each traverse. Petrography was carried out on 87 samples to aid in subdividing rhyolitic flows and units, to examine the distribution of alteration minerals and to determine the extent of their alteration. The 87 samples were analyzed by ICP-MS to provide a lithogeochemical dataset. This dataset was combined with a larger lithogeochemical dataset of 220 samples collected by George Gale during previous Manitoba Geological Survey (MGS) projects. Gale's samples cover a larger area of the BPC than those collected during this study.

Initial analysis of the geochemical data, using ratios of immobile elements (specifically TiO_2 and Zr), indicates that the mapped aphyric and quartz-phyric rhyolite are compositionally similar and are likely to have been derived from the same source. Discrete aphyric rhyolite flows, established through mapping, show no compositional variation between them. Feldspar-phyric rhyolitic flows, encountered along traverse 3, differ slightly from the aphyric and quartz-phyric rhyolitic flows to the northeast, in that they have a higher TiO_2 /Zr ratio.

Petrography was used document and monitor mineralogical and chemical changes associated with hydrothermal alteration, with the realization that the present mineral assemblages represent metamorphosed equivalents of the original hydrothermal assemblages. The abundances of sericite and chlorite, in particular, vary significantly between traverses and with respect to rhyolite-flow morphology. These minerals are common products of VMS-related hydrothermal alteration (Franklin et al., 1981; Lydon, 1984). Spatial analysis of calculated abundances of sericite and chlorite was carried out, using sericite and chlorite indices (Saeki and Date, 1980). These indices were derived from lithogeochemical data using the formulas shown in Figure GS-3-3, which document increases in the abundance of sericite based on the addition of K and increases in the abundance of chlorite based on the addition of Mg and Fe. The breakdown of plagioclase, which often occurs within the cores of hydrothermal alteration pipes, is reflected in the loss of Na and Ca from the system.

Figure GS-3-3 illustrates the spatial distribution of calculated sericite and chlorite along traverses 1 and 2 using these alteration indices. The distributions of sericite and chlorite are controlled almost exclusively by flow morphology along traverse 1, where they are most abundant within flow breccia and hyaloclastite, which may represent the most 'permeable' areas of the lobe-hyaloclastite flows. Conversely, along traverse 2, sericite and chlorite are both abundant and pervasive throughout. In this case, their distributions are not controlled by primary features or flow morphology. The distribution of sericite and chlorite along traverse 2 is interpreted to define an intense, disconformable and through-going hydrothermal system that extends through the Baker Patton VMS deposit into rhyolitic flows in the footwall to the overlying Pine Bay VMS deposits (Fig. GS-3-3).

Mineralogy established by detailed petrography was also used to aid in qualitative XRD analysis, by providing an independent means to differentiate between different minerals with similar peak intensities at similar angles of analysis. Semiquantitative XRD analysis was carried out, using the WinJade program, on whole-rock powders from samples collected during the 2001 field season and from samples previously collected by George Gale of MGS. The results of this XRD work are currently being evaluated and interpreted.

FUTURE WORK

Lithogeochemical and semiquantitative XRD data will be plotted on traverse maps at 1:3500 scale, as well as on

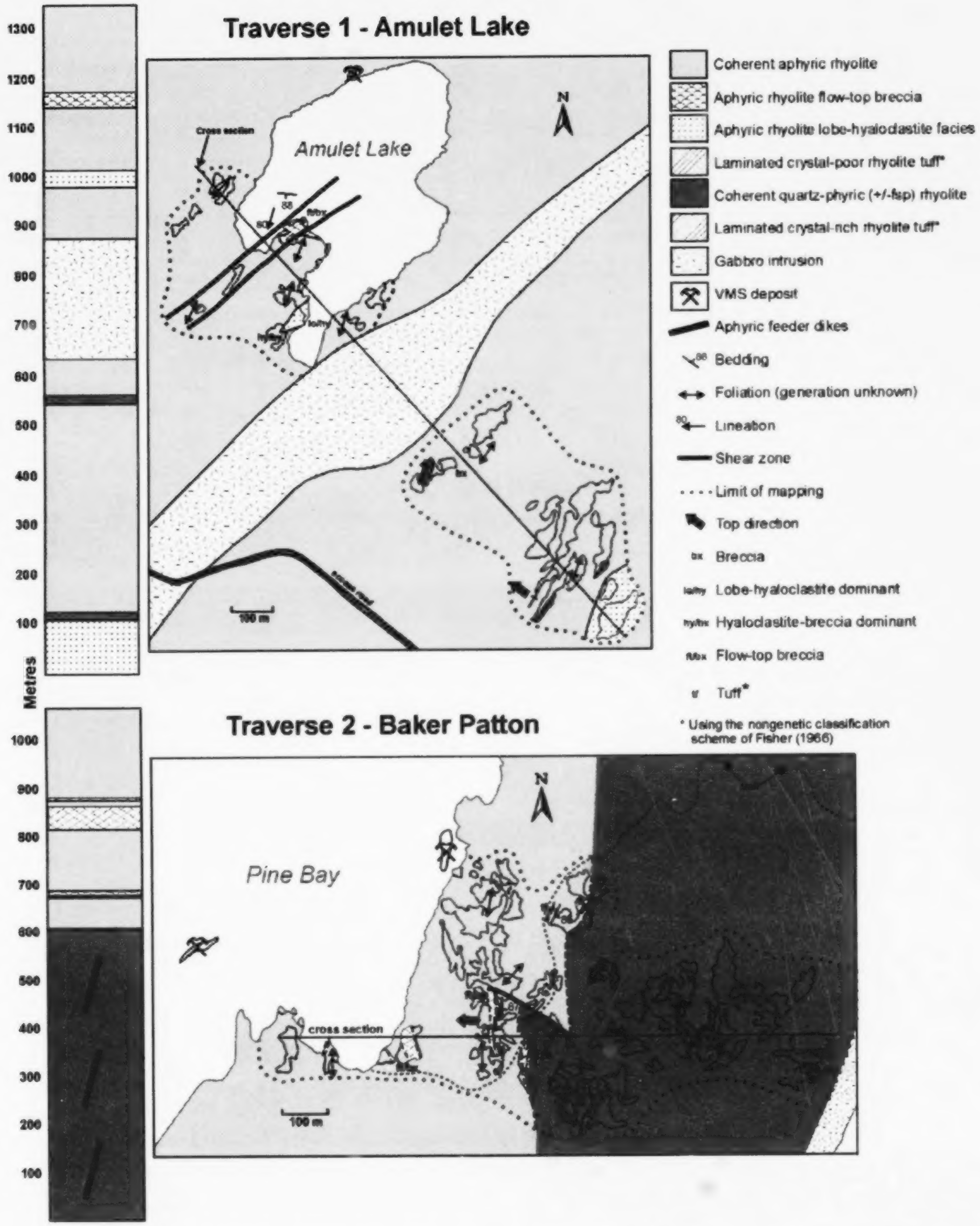

Traverse 1 - Amulet Lake
Traverse 2 - Baker Patton
Amulet Lake
Pine Bay
Cross section
cross section
N
100 m
Metres
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
Coherent aphyric rhyolite
Aphyric rhyolite flow-top breccia
Aphyric rhyolite lobe-hyaloclastite facies
Laminated crystal-poor rhyolite tuff*
Coherent quartz-phyric (+/-fsp) rhyolite
Laminated crystal-rich rhyolite tuff*
Gabbro intrusion
VMS deposit
Aphyric feeder dikes
Bedding
Foliation (generation unknown)
Lineation
Shear zone
Limit of mapping
Top direction
bx Breccia
lo/hy Lobe-hyaloclastite dominant
hy/bx Hyaloclastite-breccia dominant
ft/bx Flow-top breccia
tf Tuff*
* Using the nongenetic classification scheme of Fisher (1966)

Figure GS-3-2: Maps and schematic cross-sections of traverses 1 and 2 from the Baker Patton Complex alteration study, showing rock types and flow facies. Maps and corresponding cross-sections are not of equal scale.

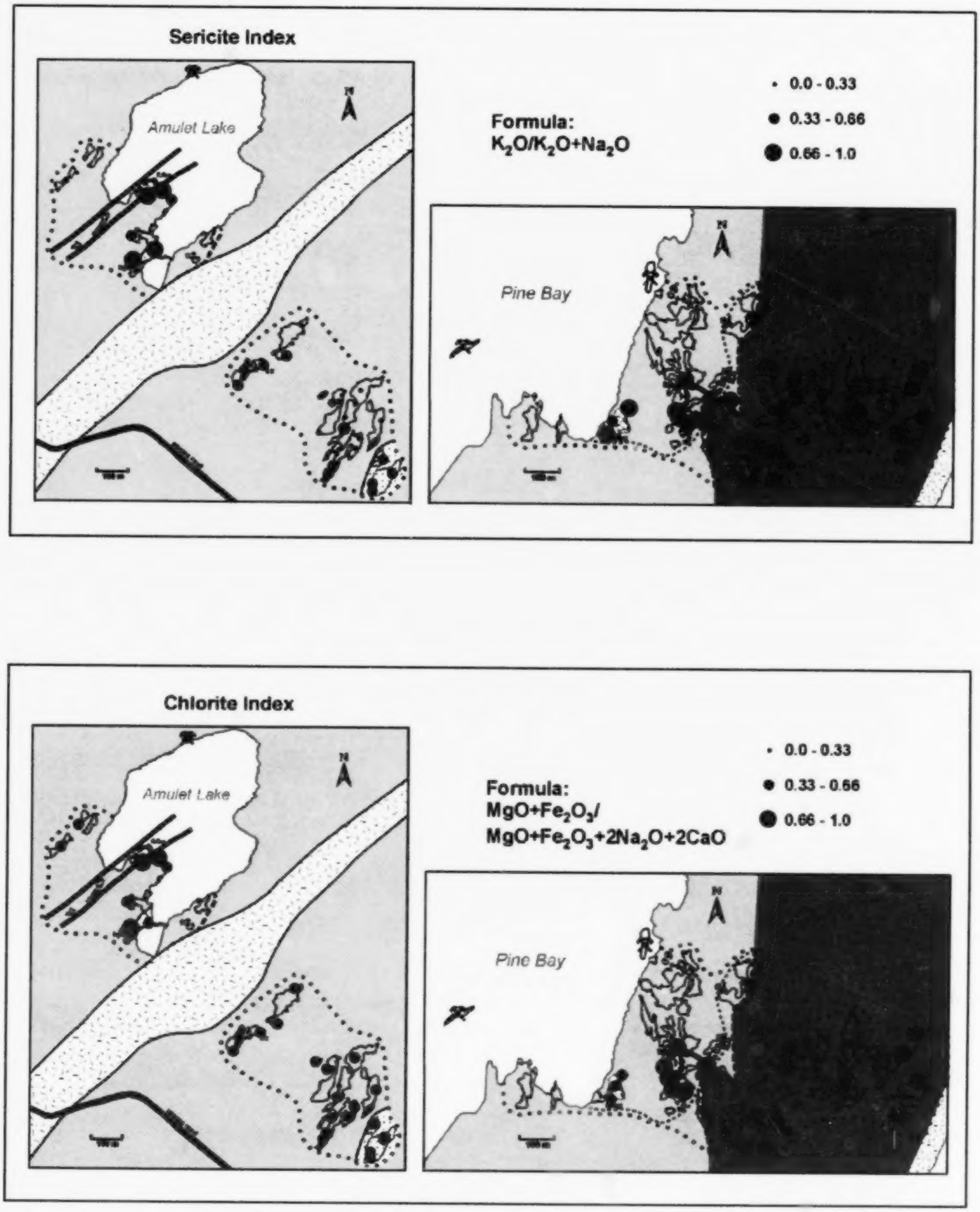

Sericite Index
Amulet Lake
N
Formula:
K2O/K2O+Na2O
• 0.0 - 0.33
● 0.33 - 0.66
● 0.66 - 1.0
Pine Bay
N
Chlorite Index
Amulet Lake
N
Formula:
MgO+Fe2O3/
MgO+Fe2O3+2Na2O+2CaO
• 0.0 - 0.33
● 0.33 - 0.66
● 0.66 - 1.0
Pine Bay
N

Figure GS-3-3: Chlorite and sericite alteration-index maps for traverses 1 and 2. Along traverse 1, high values are associated with lobe-hyaloclastite and breccia facies. Morphology appears to have no effect on the distribution and abundance of alteration minerals along traverse 2.

a larger 1:10 000-scale map of the entire BPC, and will be analyzed spatially to define and delineate areas of VMS-related hydrothermal alteration. The effectiveness of the two techniques will be compared with respect to varying scales of examination and their usefulness for delineating the known VMS deposits.

ACKNOWLEDGMENTS

This project was funded by the Geological Survey of Canada (GSC) and Laurentian University (LU). Many thanks to George Gale (MGS) for guided tours through the BPC and access to samples and lithogeochemical databases, as well as to Aur Resources Inc., especially Glen Prior and Don Dudek, for access to property maps and lithogeochemical data. Rick Syme (MGS) is thanked for interpretational help in the field. Alan Bailes (MGS) read initial drafts of the manuscript and provided many helpful suggestions. Lindsay Moeller (University of Saskatchewan), Patrick Schmidt (University of Saskatchewan) and Ben van den Berg (GSC) are gratefully acknowledged for their company and assistance in the field. Lorraine Dupuis (LU) assisted in preparing maps and Willard Desjardins (LU) prepared polished thin sections. Recent XRD work at the GSC was carried out with guidance from Andy Roberts and Brad Harvey.

REFERENCES

Bailes, A.H. and Syme, E.C. 1989: Geology of the Flin Flon–White Lake area; Manitoba Energy and Mines, Minerals Division, Geological Report GR87-1, 313 p.

Franklin, J.M., Lydon, J.W. and Sangster, D.F. 1981, Volcanic-associated massive sulfide deposits; Economic Geology, v. 75, p. 485–627.

Gale, G.H. and Dabek, L.B. 1995: The Baker Patton felsic complex (parts of NTS 63K/12 and 63K/13); *in* Report of Activities 1995, Manitoba Energy and Mines, Geological Services, p. 30–33.

Gale, G.H. and Dabek, L.B. 2002: Geology of the Baker Patton Complex, Flin Flon, Manitoba (parts of NTS areas 63K/12 and 63K/13); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Geoscientific Map MAP2002-1, scale 1:10 000.

Gale, G.H., Underhill, J. and Dabek, L. 1993: Geological investigations of the Baker Patton felsic complex (NTS 63K/12 and 63K/13); *in* Report of Activities 1993, Manitoba Energy and Mines, Geological Services, p. 50–53.

Gale, G.H., Simpson, M. and Underhill, J. 1992: Geological investigations of the Baker Patton felsic complex (NTS 63K/12 and 63K/13); *in* Report of Activities 1992, Manitoba Energy and Mines, Geological Services, p. 15–18.

Gale, G.H. and Eccles, D.R., 1988: Mineral deposits and occurrences in the Flin Flon area, NTS 63K/13: Part 1, Mikanagan Lake area (63K/13SE); Manitoba Energy Mines, Minerals Division, Mineral Deposits Series, Report 1, 133 p.

Hannington, M.D., Santaguida, F., Kjarsgaard, I.M. and Cathles, L.M. in press a: Regional greenschist facies alteration in the central Blake River Group, Western Abitibi Subprovince, Canada; Mineralium Deposita, in press, DOI 10.1007/s00126-002-0298-z

Hannington, M.D., Kjarsgaard, I.M., Galley, A.G. and Taylor, B.E. in press b: Mineral-chemical studies of metamorphosed hydrothermal alteration in the Kristineberg volcanogenic massive sulfide district, Sweden; Mineralium Deposita, in press, DOI 10.1007/s00126-002-0299-y.

Lydon, J.W. 1984: Volcanogenic massive sulphide deposits, Part 1: A descriptive model; Geoscience Canada, v. 11, p. 195–202.

Lucas, S.B., Stern, R.A., Syme, E.C., Reilly, B.A. and Thomas, D.J. 1996: Intraoceanic tectonics and the development of continental crust: 1.92–1.84 Ga evolution of the Flin Flon Belt, Canada; Geological Society of America Bulletin, v. 108, p. 602–629.

Prior, G. and Dabek, L. 1999: Geology and lithogeochemistry of the Leo Lake–Amulet Lake area, Flin Flon greenstone belt, Manitoba (NTS 63K/13SE); internal report, Aur Resources Inc., Flin Flon, Manitoba, 128 p.

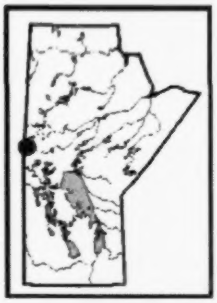
Saeki, Y. and Date, J. 1980: Computer application to the alteration data of the footwall dacite lava at the Ezuri kuroko deposits; Mining Geology, v. 30, no. 4, p. 241–250.

Stern, R.A., Syme, E.C., Bailes, A.H. and Lucas, S.B. 1995: Paleoproterozoic (1.90–1.86 Ga) arc volcanism in the Flin Flon Belt, Trans-Hudson Orogen, Canada; Contributions to Mineralogy and Petrology, v. 119, p. 117–141.

Syme, E.C. and Bailes, A.H. 1993: Stratigraphic and tectonic setting of early Proterozoic volcanogenic massive sulphide deposits, Flin Flon, Manitoba; Economic Geology, v. 88, p. 566–589.

GS-4 TRACE-ELEMENT SIGNATURES OF FLIN FLON VOLCANOGENIC MASSIVE SULPHIDE (VMS) DEPOSITS (NTS 63K, 63L), MANITOBA

by I.R. Jonasson[1], A.G. Galley[1] and D.E. Ames[1]



Jonasson I.R., Galley, A.G. and Ames, D.E. 2002: Trace-element signatures of Flin Flon volcanogenic massive sulphide (VMS) deposits, (NTS 63K, 63L), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 41–44.

SUMMARY

This aspect of the Flin Flon Targeted Geoscience Initiative deals with profiling the trace-element signatures of the Flin Flon deposits and major prospects through instrumental neutron-activation analysis (INAA), inductively coupled plasma–optical emission spectroscopy (ICP-OES) and inductively coupled plasma–mass spectrometry (ICP-MS) geochemical analysis. Major base metals, precious metals, trace and rare earth elements will be evaluated in order to investigate the relationship between deposit signatures and the geochemical profiles of their footwall rocks. The objective is to test whether exploration criteria can be based on comparisons of deposit trace-element signatures and those of their host strata.

INTRODUCTION

One of the interesting aspects of current metallogenic studies is the profiling of Canadian VMS deposits through the trace and rare earth element signatures of their host rocks and ores. These signatures are determined by the nature of the hydrothermal fluid, and by the chemistry of the footwall strata, which supply metals and other elements to the hydrothermal fluid. The chemistry of these footwall rocks can be unique to the particular tectonic environment in which the VMS deposits were formed.

The distinctive trace-element signatures of sulphide ores from VMS deposits may also be used as exploration vectors. Sulphides intercepted during drill programs or prospecting can be analyzed, and their signatures compared to the geochemical archive developed during the Flin Flon Targeted Geoscience Initiative. This can be particularly useful in determining whether a prospect lies along a known VMS-hosting stratigraphic succession, thereby allowing a more accurate assessment of the type of massive sulphide mineralization to be expected if drilling is continued.

PROGRESS REPORT

The study of some 150 ore samples from a total of 17 massive sulphide deposits (Fig. GS-4-1) and prospects in the Flin Flon camp was undertaken to provide

- *summary compositional data on ore samples for major metal components (Cu, Zn, Fe, Pb), precious metals (Au, Ag), trace metals (*see *list in Table GS-4-1) and rare earth elements:* Rock-forming elements that constitute the mainly altered, fragmental hostrock portion of the ore samples were also determined (by ICP-OES) to facilitate interpretation of the other analytical data.
- *mineralogical information on silicate and sulphide components of the ore samples:* To this end, 190 polished thin sections were prepared for petrography and electron microprobe analysis of sulphide minerals, work that is now underway.
- *analysis of sulphide and oxide mineral separates (329) derived from the ore samples:* Hand-picking and physical separation methods (superpanning, magnetic susceptibility) were employed to yield clean mineral separates of chalcopyrite, sphalerite, pyrite, pyrrhotite, magnetite and galena. These were routinely obtained, along with occasional rare components, such as tennantite and arsenopyrite. These were analyzed for the same suites of major ore-metal components, as well as trace metals, by ICP-OES, ICP-MS and wet chemical methods. Numbers of separates for individual minerals are presented, in summary form, for each deposit in Table GS-4-1. Small amounts of galena were recovered from a number of lead-bearing ores, but were not analyzed due to insufficient quantities. They were retained for possible future use in isotopic studies.
- *archive suites of sulphide ore slabs and reflected light photography of their polished surfaces:* These were prepared for distribution to the National Mineral Collection (held at GSC–Ottawa) and to the analogous collections held by the Province of Manitoba.

One of the most challenging aspects of this study is the fact that, in most cases, the VMS orebodies are hosted within

---

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, ON K1A 0E8

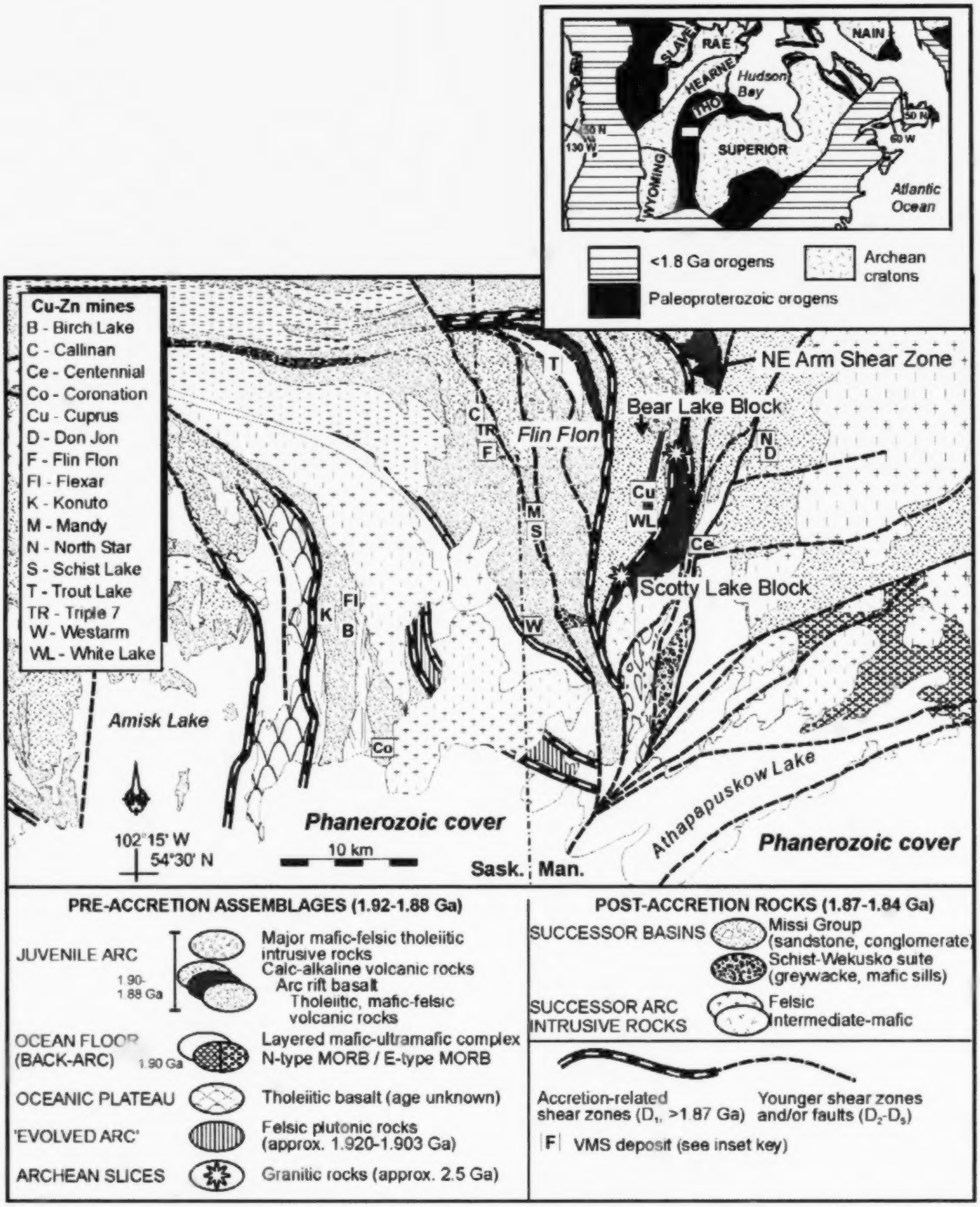

RAE
SLAVE
NAIN
HEARNE
Hudson Bay
THO
SUPERIOR
WYOMING
60 N
130 W
50 N
60 W
Atlantic Ocean
<1.8 Ga orogens
Archean cratons
Paleoproterozoic orogens
Cu-Zn mines
B - Birch Lake
C - Callinan
Ce - Centennial
Co - Coronation
Cu - Cuprus
D - Don Jon
F - Flin Flon
Fl - Flexar
K - Konuto
M - Mandy
N - North Star
S - Schist Lake
T - Trout Lake
TR - Triple 7
W - Westarm
WL - White Lake
NE Arm Shear Zone
Bear Lake Block
Flin Flon
Scotty Lake Block
Amisk Lake
Athapapuskow Lake
Phanerozoic cover
Phanerozoic cover
102°15' W
54°30' N
10 km
Sask.
Man.
PRE-ACCRETION ASSEMBLAGES (1.92-1.88 Ga)
JUVENILE ARC
1.90-1.88 Ga
Major mafic-felsic tholeiitic intrusive rocks
Calc-alkaline volcanic rocks
Arc rift basalt
Tholeiitic, mafic-felsic volcanic rocks
OCEAN FLOOR (BACK-ARC)
1.90 Ga
Layered mafic-ultramafic complex
N-type MORB / E-type MORB
OCEANIC PLATEAU
Tholeiitic basalt (age unknown)
'EVOLVED ARC'
Felsic plutonic rocks (approx. 1.920-1.903 Ga)
ARCHEAN SLICES
Granitic rocks (approx. 2.5 Ga)
POST-ACCRETION ROCKS (1.87-1.84 Ga)
SUCCESSOR BASINS
Missi Group (sandstone, conglomerate)
Schist-Wekusko suite (greywacke, mafic sills)
SUCCESSOR ARC INTRUSIVE ROCKS
Felsic
Intermediate-mafic
Accretion-related shear zones (D_1, >1.87 Ga)
Younger shear zones and/or faults (D_2-D_5)
F VMS deposit (see inset key)

Figure GS-4-1: Tectonic-assemblage map of the central portion of the Flin Flon Belt (after Lucas et al., 1996), showing the locations of producing and past-producing base-metal VMS mines.

Table GS-4-1: Summary of work undertaken on samples of sulphide mineralization collected from VMS deposits in the Flin Flon area.

Domain	Tectonics	Age (Ga)	Ore Type	Cu/ (Cu+Zn)	Host rocks for ore samples	Ores analyzed	Polished thin sections / slabs	Minerals analyzed						
								Cp	Sp	Gn	Py	Po	Mt	Asp
1) Flin Flon Assemblage	juvenile arc	1.91–1.88												
1a) Flin Flon Block	juvenile arc	ca. 1.903												
Flin Flon	arc rift, basin fill	1.903	Cu-Zn-(Pb)-(Au)	34	heterolithic fragmental and felsic flows	30	32	7	16	2	10	3	2	1
Callinan	arc rift, basin fill	1.903	Cu-Zn-(Pb)-(Au)	30	heterolithic fragmental and felsic flows	9	13	4	4	-	8	5	5	-
777	arc rift, basin fill	1.903	Cu-Zn-(Au)	36	heterolithic fragmental and felsic flows	8	12	6	1	-	3	7	3	-
Mandy	juvenile arc	1.903(inferred)	Cu-Zn-(Au)	42	heterolithic fragmental and felsic flows	12	39	13	6	-	7	2	-	-
Schist Lake	juvenile arc	1.903(inferred)	Cu-Zn-(Pb)-(Au)	38	felsic cataclastite	15	17	6	9	-	9	-	-	-
West Arm	arc rift or back arc?	<1.903?	Cu-Zn	69	cataclastite and argillite	6	7	4	-	-	3	-	-	1
1b) Bear Lake Block	juvenile arc-caldera fill	1.886			basalt and overlying cauldron infill succession									
White Lake	intra-arc rift	1.886	Cu-Zn-(Pb)	30	argillite-chert and andesitic turbidite	8	8	3	3	-	7	4	4	-
Cuprus	intra-arc rift	1.886	Cu-Zn-(Pb)	34	argillite-chert and andesitic turbidite	6	8	1	3	-	5	3	4	-
1c) Sourdough Bay Block	juvenile arc	not known												
Northstar			Cu	100	felsic cataclastics	7	8	4	-	-	7	1	-	-
Don Jon			Cu	100	felsic cataclastics	1	1	1	-	-	1	-	-	-
Pine Bay			Cu	100	augen schists, felsic (?)	7	7	6	-	-	7	2	7	-
Centennial			Cu-Zn-Pb	36	siliceous mylonites (recrystallized)	5	5	5	-	-	4	2	-	-
2) Birch Lake Assemblage	primitive juvenile arc	1.886												
			Cu-(Zn)	89	mafic flow/sill dominated	14	13	10	-	-	9	9	7	-
Flexar			Cu	100	mafic flow/sill dominated	3	4	3	-	-	1	-	3	-
Birch Lake			Cu-(Zn)	93	mafic flow/sill dominated	8	9	7	-	-	4	1	6	-
Coronation			Cu (Zn)	~90	tholeiitic basalt and associated sills	9	9	5	-	-	4	4	6	-
Konuto ***3) Successor Arc***	succesor arc	1.875–1.84												
		1.869	Cu-Zn+/-Pb	31	Fault-bounded mafic-felsic volcanics and argillites	6								
Trout Lake ***4) Vamp Lake***	setting unknown	?	Cu-Zn	~50	?	2	2	2	1	-	2	1	2	-

ICP-OES & ICP-MS (GSC Laboratories, Ottawa): SiO_2, TiO_2, Al_2O_3, Fe_2O_3(T), MnO, MgO, CaO, Na_2O, K_2O, CO_2(T), P_2O_5, S(T), Ba, LOI
Ag, Be, Bi, Cd, Co, Cr, Cs, Cu, Ga, Hf, In, Mo, Nb, Ni, Pb, Rb, Sb, Sc, Sn, Sr, Ta, Te, Th, Tl, U, V, Zn, Zr, REE

INAA (Activation Laboratories, Ancaster, Ontario): Au, As, Hg, Se, Zn (major), S(T) %

fault systems localized along stratigraphic contacts. The result is that the ores have undergone mechanical, and occasionally chemical, synkinematic remobilization. This process has most likely caused significant remobilization of base and precious metals and trace elements, which results in a very different chemical profile than that of the original orebodies. For this reason, the authors expect the most significant results to come from analysis of sulphide separates rather than aggregate ores.

SAMPLE SOURCES

Ore samples for the study were obtained from several sources. An extensive suite of relatively well preserved material was collected from dumps at defunct mines, and underground at Callinan, 777 and Konuto. Rusty rinds were removed by saw prior to further treatment. Where mine dumps have become grassy meadows as a result of a burgeoning reclamation program in the Flin Flon camp, archival collections at GSC and Hudson Bay Exploration and Development Co. Ltd. (HBED) facilities in Flin Flon were accessed. Without the extensive slab collections of D.F. Sangster, R.V. Kirkham, R.I. Thorpe and A.G. Galley, there would have been large gaps in what is now a comprehensive set of analyzed ore samples. K. Gilmore (HBED) provided a suite of underground samples from Trout Lake, and supplemented GSC suites with material from another nine deposits and prospects.

It should be noted here that an equivalent range and number of ore samples were obtained from the same sources for the Snow Lake camp (as well as the Sherridon mine), with a view to a future study of that camp for comparative purposes.

One bonus feature from this study was the discovery of some historical suites of samples collected from two of the most famous deposits in the Flin Flon camp, namely the Mandy mine (mined by open pit 1919–1920), and the Flin Flon deposit lakeshore discovery site (1919–1920) and 600-foot level (1928). These were slabbed, prepared for analysis and polished for the archival suites noted above. The ores were collected by then GSC curator A.T. McKinnon and geologist J.F. Wright. The research value of these carefully preserved samples is gratefully acknowledged. The authors trust that new archival suites derived from the present study will be of similar value to future researchers.

Table GS-4-1 provides information on deposits sampled and details on the numbers of ores and separates analyzed and the number of sections prepared for each deposit. Deposits have been grouped and arranged in an order that relates to their likely stratigraphic positions within the tectonic assembly of the Paleoproterozoic Flin Flon Belt. Geochronological data for individual deposits are sparse; those that are available are discussed in Syme et al. (1999). Geographically, the deposits cluster within discrete tectonic domains or fault-bounded slivers (Table GS-4-1). This order of listing is subjective, and merely designed to facilitate eventual presentation of analytical and mineralogical datasets. A full paper and digital database file describing results of the study are in preparation.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Manitoba Geological Survey, Hudson's Bay Exploration and Development Co. Ltd. and Hudson's Bay Mining and Smelting Co. Ltd. for their assistance in the collection of samples for this project. They would would also like to acknowledge the fact that Neil Provins, who spent many years systematically collecting samples from the mines of the Flon Flon region, has contributed his collection to the Province of Manitoba and samples to this study.

REFERENCES

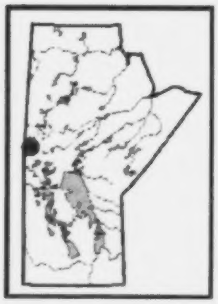
Lucas, S.B., Stern, R.A., Syme, E.C. and Reilly, B.A. 1996: Intraoceanic tectonics and the development of continental crust: 1.92–1.84 Ga evolution of the Flin Flon Belt, Canada; Geological Society of America Bulletin, v. 108, no. 5, p. 602–629.

Syme, E.C., Lucas, S.B., Bailes, A.H. and Stern, R.A. 1999: Contrasting arc and MORB-like assemblages in the Paleoproterozoic Flin Flon belt, Manitoba, and the role of intra-arc extension in localizing volcanic-hosted massive sulphide deposits; Canadian Journal of Earth Sciences, v. 36, p. 1767–1788.

GS-5

GEOLOGY OF THE ALBERTS LAKE AREA (NTS 64K13SE AND 14SW), MANITOBA

by H.P. Gilbert



Gilbert, H.P. 2002: Geology of the Alberts Lake area (NTS 63K13SE and 14SW), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 45–58.

SUMMARY

The Alberts Lake area contains parts of both the Lac Aimée and Sourdough Bay fault blocks, separated by the northeast-trending Sourdough Bay Fault. Mapping of the Lac Aimée Block in the area northwest of the fault defined a diverse assemblage of volcanic rocks akin to those in modern island arcs; these include mafic flows, volcanic fragmental rocks, felsic intrusive and minor extrusive rocks, and fine-grained turbidite deposits. In contrast, the terrane immediately southeast of the Sourdough Bay Fault, and constituting the central part of the Sourdough Bay Block, consists mainly of massive rhyolite and related breccia, with only minor basalt. This felsic volcanic terrane is separated from the north part of the Sourdough Bay Block by a granitoid terrane that extends between Alberts Lake and Naosap Lake (Preliminary Map 2002-1). The north part of the block is devoid of felsic volcanic rocks and consists largely of arc-type mafic volcanic flows, volcanic fragmental rocks and subordinate turbidite deposits. Lithostratigraphic differences between the central and north parts of the Sourdough Bay Block suggest these terranes may be separate tectonostratigraphic units. New geochemical data is expected to clarify the origin and affinities of the volcanic rocks within the Sourdough Bay Block.

INTRODUCTION

A five-week field program was focused on the central and north parts of Alberts Lake and the contiguous area between Alberts Lake and Lac Aimée (Fig. GS-5-1, GS-5-2; Table GS-5-1). Preliminary Map 2002-1 is a compilation of the results of field mapping in 1996, 1997 and 2002; geological data in the south-central part of the map are the result of mapping in the current (2002) study area. The objectives of the project are to

- upgrade existing geological maps in the north part of the Flin Flon Belt by Bateman and Harrison (1945) and Kalliokoski (1949), and provide continuity between two recently mapped areas at Lac Aimée and Naosap Lake (Gilbert, 1999, Open File Map OF99-1);
- study the structure, stratigraphy and volcanic geochemistry of the area, in order to assess the tectonostratigraphic and economic significance of volcanic rock assemblages; and
- investigate mineralized localities and assess their economic significance.

The current map area (shown in Fig. GS-5-2) is bisected by the Sourdough Bay Fault, a major northeast-trending, block-bounding feature that separates southeast-facing, mainly mafic volcanic rocks to the northwest (Lac Aimée Block) from a west- to northwest-facing, mainly felsic volcanic sequence to the southeast (Sourdough Bay Block). The Lac Aimée Block is deformed in a southwest-plunging synclinorial structure delineated by regional foliation trends and sporadic top indicators, such as graded bedding and pillow structure (Fig. GS-5-3). Southeast of the Sourdough Bay Fault, according to the limited structural data available, the felsic volcanic terrane in the Sourdough Bay Block forms a west- to northwest-facing homocline.

Felsic volcanic rocks in the Sourdough Bay Block are in gradational contact with an ovoid tonalitic intrusion to the northeast, suggesting the intrusion is synvolcanic and genetically related to the volcanic rocks. South of Alberts Lake, a massive gabbro intrusion with subordinate granitoid phases separates the volcanic terrane at Alberts Lake from the south part of the Sourdough Bay Block (Fig. GS-5-1).

REGIONAL SETTING

The Sourdough Bay fault block is one of the most extensive tectonic components in the Flin Flon Belt (Figs. GS-5-1) and extends laterally for approximately 28 km from the area north of Naosap Lake to Athapapuskow Lake in the south (Bailes and Syme, 1989). The north part of the Sourdough Bay Block, in the vicinity of Naosap Lake, contains arc-type mafic volcanic flows, volcanic fragmental rocks and subordinate turbidite deposits (Gilbert, 1997). The central part of the fault block at Alberts Lake, in contrast, consists mainly of felsic volcanic rocks, whereas south part (at northern Athapapuskow Lake) consists of a lithologically diverse assemblage of mafic to intermediate flows, felsic to mafic volcaniclastic rocks, and sedimentary deposits (Bailes and Syme, 1989). Felsic volcanic rocks are predominant in the south part of the Sourdough Bay Block (Baker Patton Complex; Bailes and Syme, 1989); the felsic complex contains one gold deposit and at least seven massive sulphide deposits (Gale and Dabek,

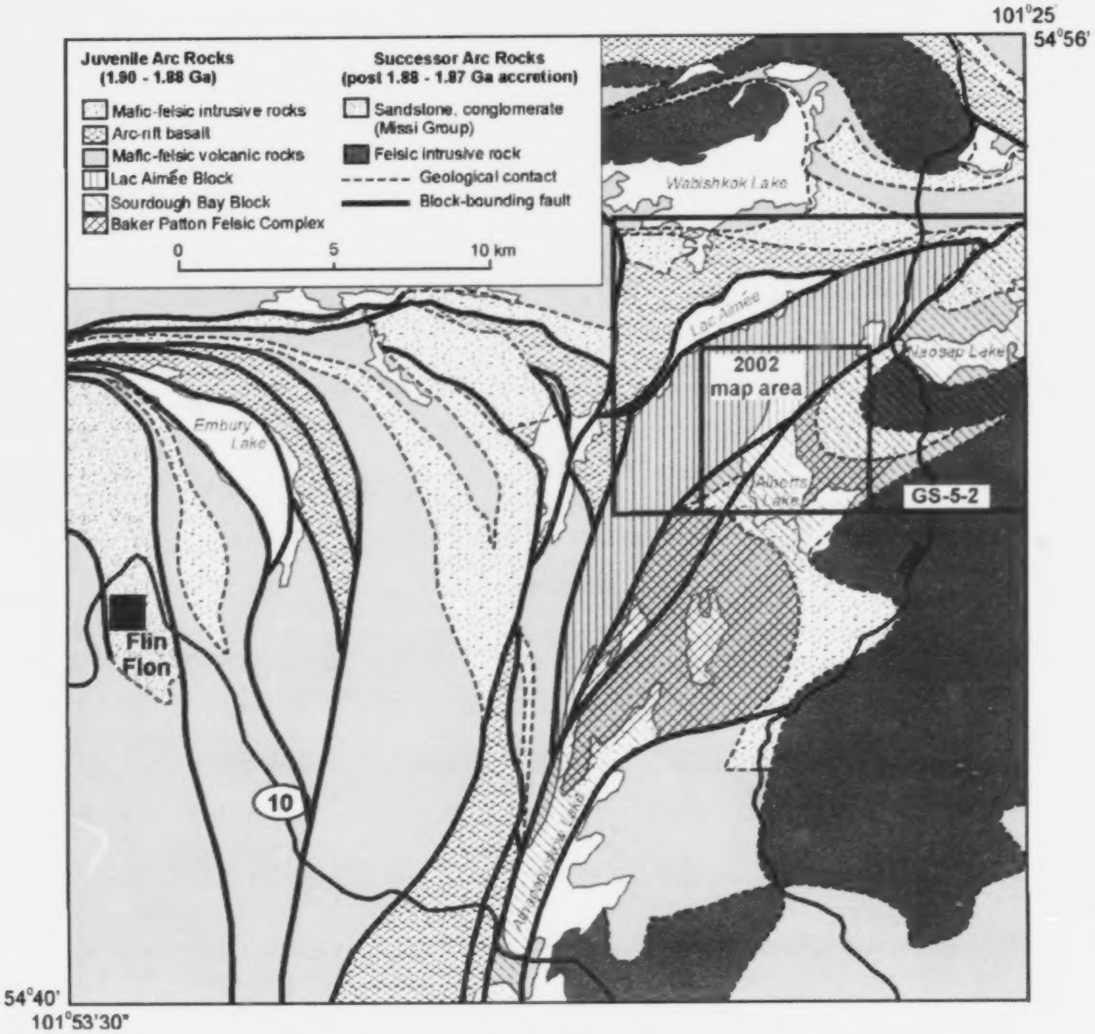

101°25'
54°56'
Juvenile Arc Rocks (1.90 - 1.88 Ga)
Mafic-felsic intrusive rocks
Arc-rift basalt
Mafic-felsic volcanic rocks
Lac Aimée Block
Sourdough Bay Block
Baker Patton Felsic Complex
Successor Arc Rocks (post 1.88 - 1.87 Ga accretion)
Sandstone, conglomerate (Missi Group)
Felsic intrusive rock
Geological contact
Block-bounding fault
0
5
10 km
Wabishkok Lake
Lac Aimée
Naosap Lake
2002 map area
Alberts Lake
GS-5-2
Embury Lake
Flin Flon
10
Athapapuskow Lake
54°40'
101°53'30"

Figure GS-5-1: Simplified geology of the south-central part of the Flin Flon Belt.

2002) — a significant fact for any future economic assessment of the felsic volcanic terrane in the central part of the block at Alberts Lake. Structural data in both the south and central parts of the Sourdough Bay Block indicate that the sequence is a west- to northwest-facing homocline.

STRUCTURE

Five deformation periods (Table GS-5-2) have been recognized in the Lac Aimée–Naosap Lake area (Gilbert, 1997), all of which postdate the 1.88–1.87 Ma tectonic accretion of the Amisk collage (Lucas et al., 1996). The earliest deformation event produced north- to west-trending major F_1 folds and an associated regional foliation in the area northeast of Lac Aimée (Animus Lake Block in Fig. GS-5-2; Fig. GS-5-3). This early deformation event is also responsible for the regional foliation (S_1) in the study area at Alberts Lake, but no early (F_1) folds have been identified. The S_1 foliation is deformed by west- to southwest-plunging F_2 folds in the Lac Aimée Block (Lac Aimée synclinorium in Fig. GS-5-3). The F_2 synclinal fold that extends through Eagle Head Lake is especially well defined by the trends of both S_1 foliation and S_0 (volcanic flows and sedimentary layering). A predominantly south-southwest-plunging L_2 lineation occurs in both the Lac Aimée and Sourdough Bay blocks.

Major northwest-trending, open F_3 folds deform the axial traces of F_2 folds in the Lac Aimée synclinorium. This deformation event also produced an associated S_3 strain-slip cleavage that occurs sporadically within volcanic-derived

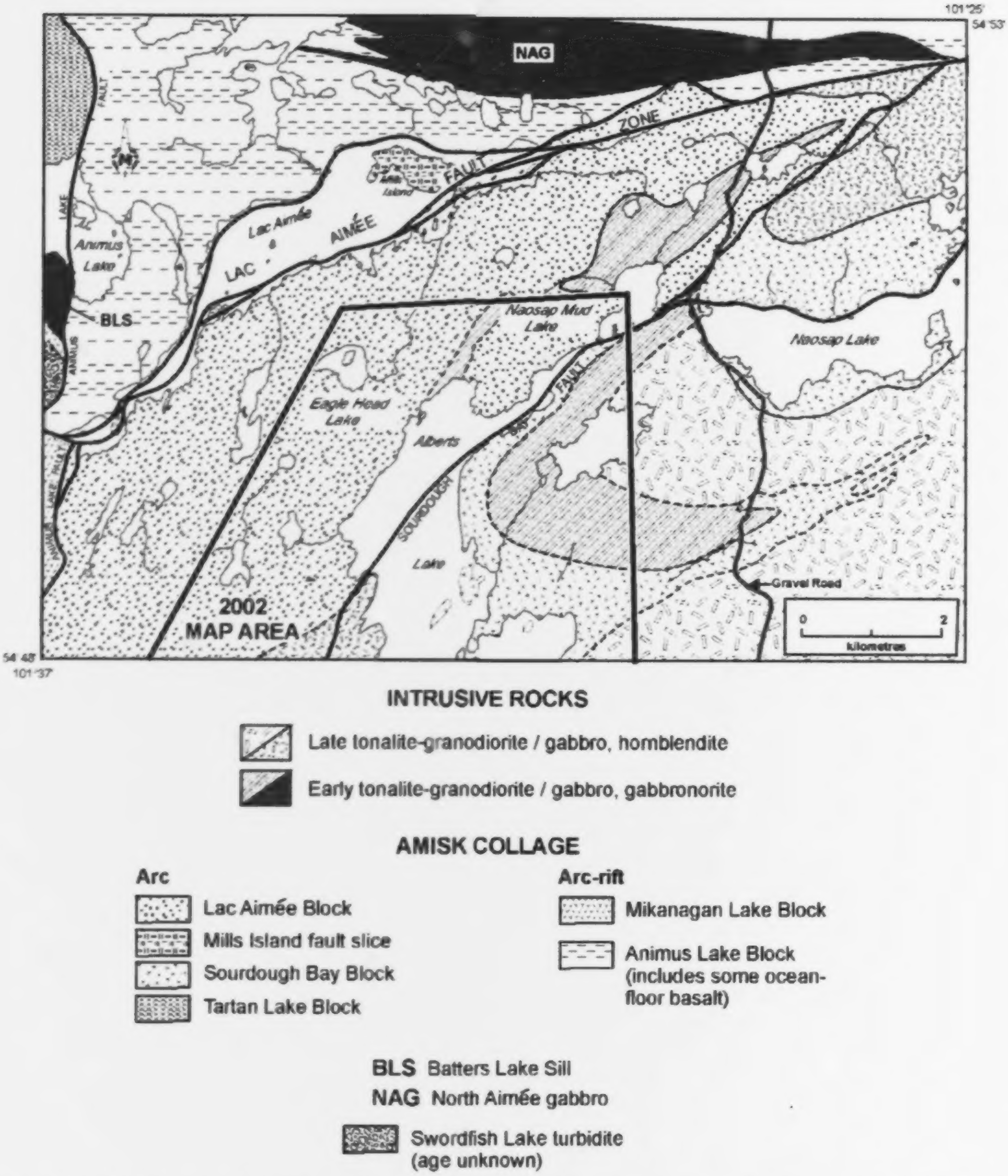

101°25'
54°53'
NAG
ZONE
FAULT
LAC
AIMÉE
Lac Aimée
Mills Island
Animus Lake
LAKE
FAULT
ANIMUS
BLS
N
Naosap Mud Lake
Naosap Lake
Eagle Head Lake
Alberts
Lake
SOURDOUGH
BAY
FAULT
ANIMUS LAKE FAULT
Gravel Road
0
2
kilometres
2002 MAP AREA
54°48'
101°37'
INTRUSIVE ROCKS
Late tonalite-granodiorite / gabbro, hornblendite
Early tonalite-granodiorite / gabbro, gabbronorite
AMISK COLLAGE
Arc
Lac Aimée Block
Mills Island fault slice
Sourdough Bay Block
Tartan Lake Block
Arc-rift
Mikanagan Lake Block
Animus Lake Block (includes some ocean-floor basalt)
BLS Batters Lake Sill
NAG North Aimée gabbro
Swordfish Lake turbidite (age unknown)

Figure GS-5-2: Main structural subdivisions, tectonic features and intrusive units in the Lac Aimée–Naosap Lake–AlbertsLake area.

schist and fine-grained sedimentary rocks (Gilbert, 1997).

The D_4 deformation is most prominently manifested as a northeast-trending open fold in the Animus Lake Block. This deformation event, which is attributed to sinistral movement along the Flin Flon–Kisseynew boundary during crustal-scale deformation of the Amisk collage (Ashton, 1993), is not recognized within the Lac Aimée and Sourdough Bay fault blocks.

The D_5 brittle deformation produced strike-slip shears and faults at high angles to the regional foliation that are commonly associated with pronounced topographic lineaments. Reactivation of early major faults (e.g., the northeast-trending Sourdough Bay Fault) probably also occurred during D_5. This early block-bounding structure juxtaposes the stratigraphically and structurally contrasting Lac Aimée and Sourdough Bay fault blocks (Fig. GS-5-2). Whereas the

Table GS-5-1: Table of formations in the Lac Aimée–Naosap Lake–Alberts Lake area.

	PRECAMBRIAN
Post 1.88 Ga intrusive rocks	
12	*Diabase, (aphyric to plagioclase phyric)*
11	*Tonalite, granodiorite; granite, aplite*
10	Gabbro, minor hornblendite
Amisk Collage	
Intrusive rocks – synvolcanic or penecontemporaneous with 1.88 Ga volcanism (may include <1.88 Ga intrusive rocks)	
9	Mafic intrusive rocks: gabbro, gabbronorite, hornblendite, leucogabbro, diabase
8	Felsite, plagioclase-quartz porphyry
7	Tonalite, leucotonalite, quartz diorite; granodiorite, granite; minor diorite
Volcanic and sedimentary rocks	
Lac Aimée and Sourdough Bay arc and arc-rift volcanic rocks; related turbidite-type sedimentary rocks	
6	Feldspathic greywacke, siltstone, siliceous siltstone, argillite, oxide facies iron formation
5	Rhyolite (plagioclase±quartz phyric); rhyolite breccia; minor felsic tuff
4	Basalt, basaltic andesite (aphyric to plagioclase±pyroxene phyric); volcanic breccia, tuff and diabase; related schist and gneiss
	Fault contact
Animus Lake mafic volcanic rocks (inferred arc-rift and ocean-floor in origin); minor related sedimentary rocks	
3	*Basalt (aphyric); minor plagioclase-phyric basalt, tuff, breccia and diabase; sulphide facies iron formation, feldspathic greywacke, siltstone*
	Fault contact
Tartan Lake arc-type basalt	
2	*Basalt (aphyric to plagioclase phyric)*
	Fault contact
Mikanagan Lake arc-rift basalt	
1	*Basalt (aphyric); minor spherulitic, plagioclase±pyroxene-phyric basalt and diabase*

Note. Unit 6 may include sedimentary rocks that postdate 1.88 Ga volcanism. The relative ages between units 10, 11 and 12 and between units 7, 8, and 9 are not determined.

fault is thought to have originated during tectonic accretion prior to D_1, tectonic transport and final emplacement of the Lac Aimée Block within the Amisk collage was probably only completed just prior to D_2 (Gilbert, 1997). Repeated movement along the Sourdough Bay Fault is inferred from the fabric of tectonic breccia in the northeast part of the map area, which contains diverse, tectonically laminated and randomly oriented blocks (Gilbert, 1996). The fault is related to other block-bounding structures elsewhere in the Flin Flon Belt that were initiated during tectonic accretion of the Amisk collage, and underwent subsequent reactivation (Syme, 1995).

STRATIGRAPHY

The geology of parts of both the Lac Aimée and Sourdough Bay fault blocks has been previously described (Gilbert, 1986, 1996, 1997). The geological units described in this report occur within the current (2002) map area centred on Alberts Lake (i.e., the southeast flank of the Lac Aimée Block and the central part of the Sourdough Bay fault block; Fig. GS-5-2). Numbers in parentheses correspond to unit numbers in Preliminary Map 2002-1.

Lac Aimée Block

Basalt, basaltic andesite, aphyric to plagioclase phyric, pillowed to massive; minor related volcanic breccia, diabase and gabbro (unit 4a)

Massive basalt flows and related fragmental rocks are the predominant lithological types in the Lac Aimée fault

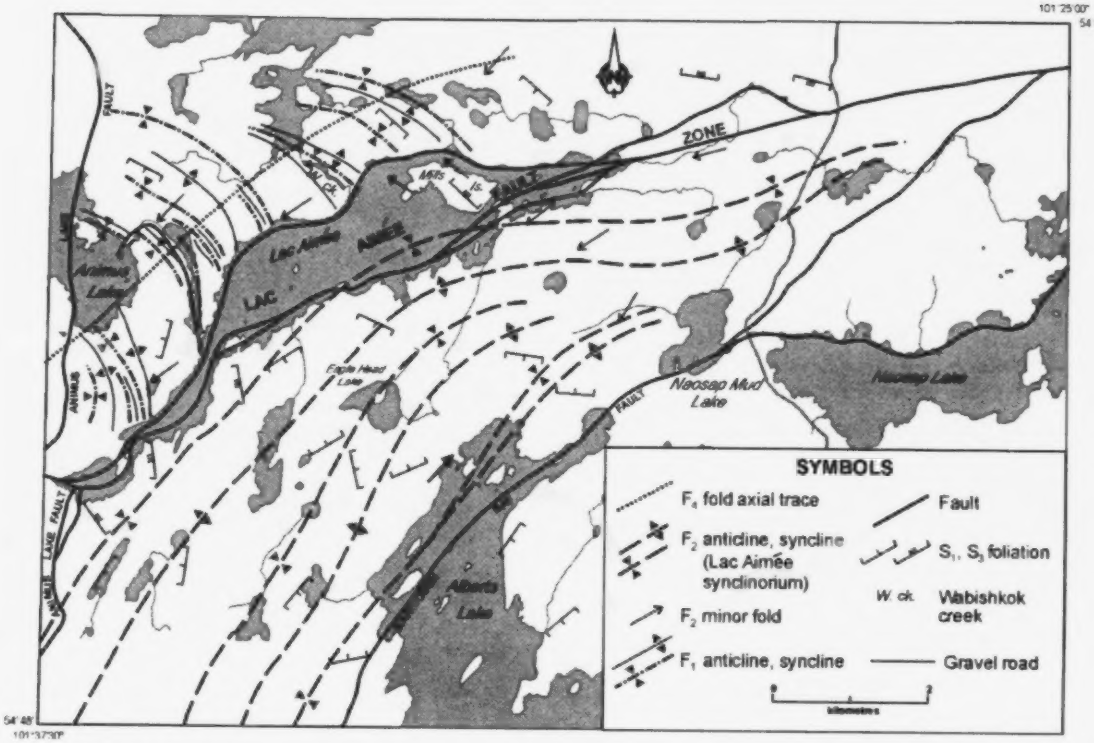

101°25'00"
54°53'00"
FAULT
ZONE
FAULT
Mills Is.
W. ck.
Lac Aimée
AIMÉE
LAC
Animus Lake
ANIMUS
Eagle Head Lake
Naosap Mud Lake
Naosap Lake
FAULT
Alberts Lake
ANIMUS LAKE FAULT
SYMBOLS
F4 fold axial trace
F2 anticline, syncline (Lac Aimée synclinorium)
F2 minor fold
F1 anticline, syncline
Fault
S1, S3 foliation
W. ck. Wabishkok creek
Gravel road
0
2
kilometres
54°48'
101°37'30"

Figure GS-5-3: Major structural elements in the Lac Aimée–Naosap Lake–Alberts Lake area.

Table GS-5-2: Deformation history in the Lac Aimée–Naosap Lake–Alberts Lake area (post 1.88–1.87 Ga tectonic accretion of the Amisk collage).

D_1	Regional west- to southwest-trending S_1 foliation; inferred related major folds in Lac Aimée block. Juxtaposition of Lac Aimée and Sourdough Bay fault blocks along Sourdough Bay Fault preceded and/or accompanied D_1. Major tight to isoclinal F_1 folds with moderately to steeply dipping axial planes (overturned to northeast) occur in Animus Lake block (northwest of Lac Aimée Block).
D_2	Tight to isoclinal major folds (west- to southwest-plunging Lac Aimée synclinorium in Lac Aimée Block). Minor folds and lineations plunge west to southwest and northeast.
D_3	Major, northwest-trending open folds result in warping of axial traces of F_2; associated S_3 strain-slip cleavage.
D_4	Northeast-trending open fold in the Animus Lake Block, attributed to sinistral movement along the Flin Flon–Kisseynew boundary (not recognized in Lac Aimée and Sourdough Bay blocks).
D_5	Brittle faulting and shearing within fault blocks. Reactivation of early block-bounding structures (e.g., Sourdough Bay Fault).

block. These volcanic rocks, which are geochemically akin to modern arc and arc-rift rocks (Gilbert, 1997), include diverse pillowed and massive flows intercalated with amygdaloidal breccia (unit $4a_3$) that is locally predominant toward the southeast margin of the fault block. The mafic rocks are largely aphyric, but sparsely plagioclase-phyric flows occur sporadically. The mafic volcanic sequence attains a thickness of approximately 1 km at the north end of Alberts Lake.

Pillowed basalt (unit 4a) is well preserved in the core of the syncline at Eagle Head Lake, where the volcanic flow trends define the trace of the major fold (Preliminary Map 2002-1). The pillows at that locality are typically 0.4 to 2 m in size, locally undeformed and provide unequivocal tops (Fig. GS-5-4). The flows are mainly aphyric and weather grey-green to beige-grey; thermal contraction fractures at pillow margins are not uncommon, whereas polygonal cooling joints are comparatively rare. The majority of mafic flows in the Eagle Head Lake area are not conspicuously amygdaloidal, but some units contain quartz or altered plagioclase amygdules ranging in size from fine (0.3–0.8 mm) to medium grained (1–2 mm). Amygdaloidal units are locally intercalated with flow-breccia and nonvesicular flows at a scale of 2 to 10 m.

Figure GS-5-4: Stratigraphic tops at the shore of Eagle Head Lake are indicated by an undeformed pillow and an open vug with concave upper surface.

Plagioclase-phyric mafic units (phenocrysts 1–3 mm, 10–30% of the rock) up to 50 m thick are intercalated with aphyric basalt in the southwest part of the map area, close to the contact with gabbro (10). Most of these units are interpreted as diabase sills (9e), but pillowed plagioclase-phyric basalt and related breccia (4a) also occur at that locality. One unit is megaphyric, with localized concentrations of euhedral plagioclase phenocrysts (up to 2.5 x 4 cm, 10–35% of the rock).

In the north part of Alberts Lake, mafic volcanic rocks are characterized by an abundance of fragmental rocks relative to massive flows; both rock types are typically amygdaloidal. The majority of both the fragmental and massive rocks contain 10 to 50% ovoid quartz amygdules (typically 0.1–1 cm), but the amygdaloidal texture is locally coarser (0.5–3 cm) and large open vugs (3–8 cm wide) are not uncommon. Subordinate amygdule types are filled with plagioclase (±quartz) or hornblende (±chlorite). Disseminated pyrite constitutes 1 to 5% of the basaltic rocks and interpillow chert occurs in a few units. Pillow structure is commonly deformed or disrupted, both by volcanic and subsequent tectonic processes, and thus reliable stratigraphic top indicators are sparse in the north part of Alberts Lake. Pillowed flows are locally moderately epidotized and, less commonly, strongly silicified.

Basaltic breccia (unit $4a_3$) underlies an island approximately 180 m wide in the north part of Alberts Lake (Preliminary Map 2002-1). The fragmental rock, which is lithologically identical to flow-breccia units (1–12 m thick) that are intercalated with pillowed basalt flows, is essentially monolithic; clasts are basaltic and differ only in their amygdaloidal texture. Sporadic, rare siliceous fragments are interpreted as altered mafic volcanic types that could represent silicified parts of a source flow unit. The unsorted breccia is matrix- to clast-supported and densely amygdaloidal; angular to subrounded fragments are typically 3 to 10 cm long (up to 30 cm) and constitute 30 to 75% of the rock.

Intermediate to mafic heterolithic breccia, minor tuff (unit 4c)

A formation of reworked volcanic fragmental deposits up to 230 m thick extends laterally for approximately 2.5 km within the mafic volcanic sequence northwest of Alberts Lake. The unit thins to the southwest and wedges out in the area south of Eagle Head Lake. To the northeast, the formation is laterally gradational with mafic tuff and derived turbidite that extend around the north end of Alberts Lake to Naosap Mud Lake and beyond, to the fold closure of the Lac Aimée synclinorium in the northeast corner of the map area (Preliminary Map 2002-1).

Heterolithic volcanic breccia contains diverse fragments of basalt (amygdaloidal to nonamygdaloidal, variously epidotized) and plagioclase±quartz–phyric felsic types that locally contain lenticular chloritic aggregates. The unsorted clasts are subangular to angular, moderately to strongly attenuated, and range in size from lapilli to larger fragments (0.2–0.5 m) and sporadic blocks (up to 1 x 0.15 m). Fine- to coarse-grained tuffaceous interlayers (±lapilli) are 0.2 to 5 m thick and commonly diffusely laminated or well bedded at a scale of 1 to 20 cm. The tuff, which is lithologically identical to the matrix of heterolithic breccia, locally displays southeast-facing graded bedding (defined by feldspathic grains and locally lapilli); siliceous laminae (0.5–2 cm) occur in the upper parts of some units. In contrast, some mafic tuff layers are massive and homogeneous over intervals of 3 m or more.

The volcanic fragmental rocks (unit 4c) are interpreted as redeposited by subaqueous debris flows and turbidity currents. The lack of sorting in heterolithic breccia, the angular fragment shapes and the occurrence of sporadic large blocks are consistent with a mass-flow mode of emplacement. The stratigraphic association of sedimentary rocks with the breccia indicates a subaqueous depositional environment. Diffuse to well-defined bedding and grading in tuffaceous interlayers within the breccia are attributed to reworking by turbidity currents.

Felsic volcanic rocks (unit 5)

Felsic porphyritic rocks occur in several lensoid units within the predominantly mafic volcanic terrane in the southeast part of the Lac Aimée Block. These rocks are mainly massive and homogeneous, in contrast to the essentially fragmental felsic volcanic units in the Sourdough Bay Block (Preliminary Map 2002-1). The felsic units are lithologically akin to minor felsic porphyry dikes and sills (unit 8), but definitive evidence for their origin (intrusive vs. extrusive) is largely absent. For example, a 180 m wide unit in the southwest part of the map area consists of a coarsely porphyritic rock with large quartz and plagioclase phenocrysts (0.5–1 cm, each up to 15% of the rock) and up to 5% pyritohedra; the porphyritic texture is locally less coarse grained, but otherwise the unit is homogeneous and its origin (sill or flow) cannot be ascertained.

The felsic unit southeast of Eagle Head Lake (Preliminary Map 2002-1) is also mainly homogeneous, but is interpreted as extrusive because it contains an 8 m wide, monolithic fragmental zone with attenuated lapilli-size clasts and sporadic blocks up to 15 by 1 cm. This unit is sparsely plagioclase-quartz phyric (phenocrysts are 0.2–0.8 mm, 5–10% of the rock) and lithologically similar to some porphyritic dikes (unit 8a). The moderately to strongly foliated felsic rocks of unit 5 predate the regional (S_1) foliation and are interpreted as volcanic in origin; they probably include both intrusive and extrusive rock types.

A fragmental rhyolite flow (unit 5c, 5a) occurs at an island in the west-central part of Alberts Lake, close to the southeast margin of the Lac Aimée Block. The felsic flow is at least 12 m thick and overlies densely amygdaloidal, highly altered and mineralized pillowed basalt to the northwest (see 'Economic Geology' section). The fragmental unit (Fig. GS-5-5) is monolithic and consists largely of angular to tabular blocks (10–40 cm, up to 0.25 x 0.5 m) and sporadic rhyolite lobes up to 2 m long that together constitute 40 to 65% of the rock. The clasts are plagioclase phyric (0.5–3 mm, 5–25% of the rock) and a minority contain elongate chloritic amygdules (1–7 mm long, up to 20% of the rock). The breccia is lithologically gradational with a subordinate massive rhyolite zone (approximately 2 m wide) within the fragmental unit, which is assumed to represent the brecciated margin of a cooling lava flow.

Feldspathic greywacke, siltstone (unit 6a)

Fine-grained sedimentary rocks, interpreted as reworked tuffaceous deposits, occur along strike from heterolithic volcanic breccia (unit 4c) in the area north of Alberts Lake. This southeast-facing sedimentary formation is up to 425 m thick and extends for approximately 8 km along strike, from northwestern Alberts Lake to the northeast corner of the map area (Preliminary Map 2002-1).

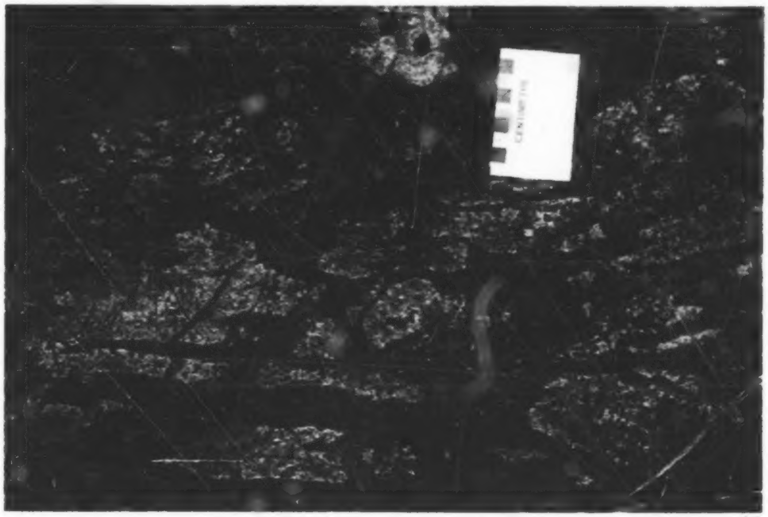


Figure GS-5-5: Rhyolite breccia (unit 5c) in the west-central part of Alberts Lake. Angular to amoeboid fragments are interpreted as the result of brecciation at the margin of a cooling lava flow.

Feldspathic greywacke and siltstone occur both as massive deposits (up to 4 m thick) and as well-bedded units with layering on a 0.5 to 20 cm scale. Fine detrital feldspathic grains (0.3–1.0 mm) are preserved in the greywacke, which locally displays normal size grading over the basal 10 to 40 cm zone of a bed, transitional upward to siltstone. Scour by greywacke into underlying finer grained sedimentary rocks also locally indicates top directions (Fig. GS-5-6).

Hornblende-chlorite porphyroblastic aggregates (1–3 mm, 15% of the rock) occur in a few siltstone units. Pale green to cream-weathering, thinly laminated siliceous siltstone (4–12 cm thick) at the top of some units is interpreted as derived, in part, from chert. Rare siltstone rip-ups within greywacke beds and sporadic graded bedding in these units are attributed to deposition by turbidity currents.

Sourdough Bay Block

Mafic volcanic rocks (unit 4)

Basaltic flows and related fragmental rocks constitute less than 10% of the central part of the Sourdough Bay Block. Enclaves of the mafic rocks occur within the predominantly felsic volcanic terrane north of the southeast bay of Alberts Lake, and also at the northwest margin of the tonalite intrusion (unit 7a) east of the lake (Preliminary Map 2002-1). Contact relations between the felsic and mafic volcanic rocks were rarely observed; at one locality, rhyolite breccia (unit 5c) truncates the fabric of an older basaltic unit (Fig. GS-5-7). Elsewhere, volcanic enclaves are fault bounded; a 15 by 3.5 m tectonic lens of rhyolite breccia occurs within basalt (unit 4a) at one locality very close to the

CENTIMETRE

Figure GS-5-6: Scour of siliceous siltstone by overlying feldspathic greywacke (unit 6a) in the turbidite formation north of Alberts Lake.

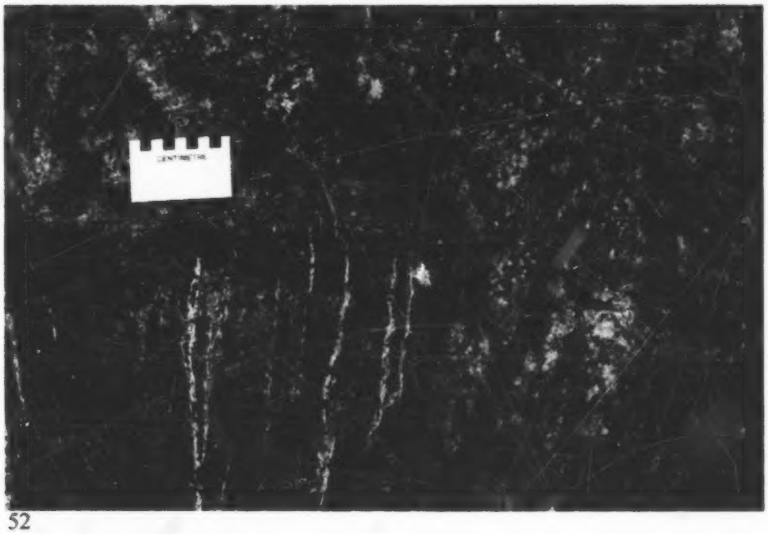


Figure GS-5-7: Contact between basalt (unit 4a) and rhyolite breccia (unit 5c), southeastern bay of Alberts Lake. The basaltic foliation and associated early quartz veins are truncated by the younger felsic rock.

eastern extremity of Alberts Lake. The Sourdough Bay basaltic flows are locally intercalated with both flow-breccia (units $4a_2$, $4a_3$) and coarse, heterolithic debris-flow deposits (unit 4c).

Pillowed to massive basaltic flows and related breccia (unit 4a) in the central part of the Sourdough Bay Block are lithologically similar to those in the Lac Aimée Block (*see* above). Moderately flattened pillows in the Sourdough Bay basalt (1–2 m long) indicate west-facing tops; megapillows (up to 5 x 1.7 m) occur at several localities in the southeast part of Alberts Lake. The mafic flows are aphyric to locally sparsely plagioclase phyric (<5% phenocrysts); amygdaloidal texture is common but amygdules (mainly quartz) are generally smaller and less abundant than in the Lac Aimée basalt. Some units display very coarse amygdaloidal texture; for example, conspicuous spheroidal epidote amygdules (0.5–3.5 cm) occur in one flow that is extensively epidotized. The coarsely amygdaloidal unit is associated with related breccia interlayers, gabbro and diabase within a 90 m wide enclave in the felsic volcanic terrane east of Alberts Lake.

Aphyric basalt flows at the northeast shore of Alberts Lake are intercalated with plagioclase-phyric diabase units (phenocrysts 0.5–2 mm, 10–25% of the rock) that constitute approximately 20% of the section. Whereas these flows are unaltered, amygdaloidal pillowed basalt further south, at an islet just east of the (projected) Sourdough Bay Fault, contains 15 to 35% ovoid epidosite pods (up to 60 cm long) that are derived from the altered cores of pillows (Fig. GS-5-8).

Mafic tuff (unit 4b) in association with chert (unit 6b) occurs at two localities within the felsic volcanic terrane at the southeast shore of Alberts Lake. At the east shore of Christie's island[1] (Preliminary Map 2002-1), a dark green weathering, locally iron-stained mafic tuff unit contains a 12 cm thick, disrupted layer of white chert. Only the west margin (0.5 m thick) of the tuff deposit is accessible at the shore, but the unit is estimated to be only a few metres thick on the basis of the known stratigraphy along strike. The contact between the tuff and rhyolite breccia to the west has been intruded by a concordant diabase unit (9–15 m thick). A second mafic tuff-chert occurrence within the felsic volcanic terrane is located approximately 1 km north of Christie's island. The 3 m thick unit consists of fine-grained chloritic tuff that contains subordinate chert interlayers; the chert is locally magnetiferous and partly folded and disrupted. The well-foliated tuff is characterized by ovoid secondary epidosite domains (2–10 cm, 10–30% of the rock). A 15 m wide aphyric basalt unit occurs along strike from the mafic tuff.

Heterolithic volcanic breccia (unit 4c) is intercalated with massive, quartz amygdaloidal basalt and flow-breccia at the southeast bay of Alberts Lake. The unit is unsorted, matrix- to clast-supported, and contains fragments of aphyric basalt (variously amygdaloidal) and subordinate rhyolite (variously plagioclase phyric); clasts are subangular to angular and typically range from lapilli to small blocks (1–10 cm). Sporadic blocks of coarsely amygdaloidal basalt up to 0.5 by 1 m are also incorporated in the fragmental deposit, which is interpreted as a debris flow. An adjacent outcrop, interpreted as a different debris flow, consists of a partly disrupted, diffusely laminated, mafic volcanic rock (either basalt or tuff). The deposit contains rafted mafic blocks (up to 0.5 x 1 m) and smaller rhyolite fragments within a mafic matrix (Fig. GS-5-9).

---

[1] unofficial name

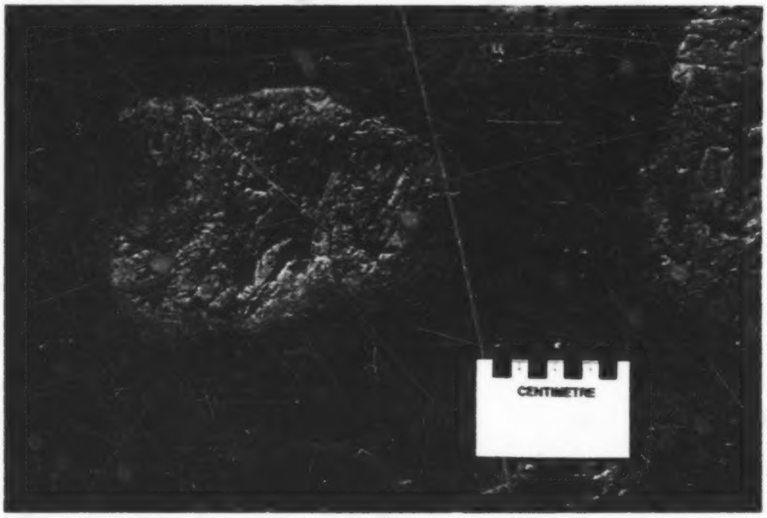
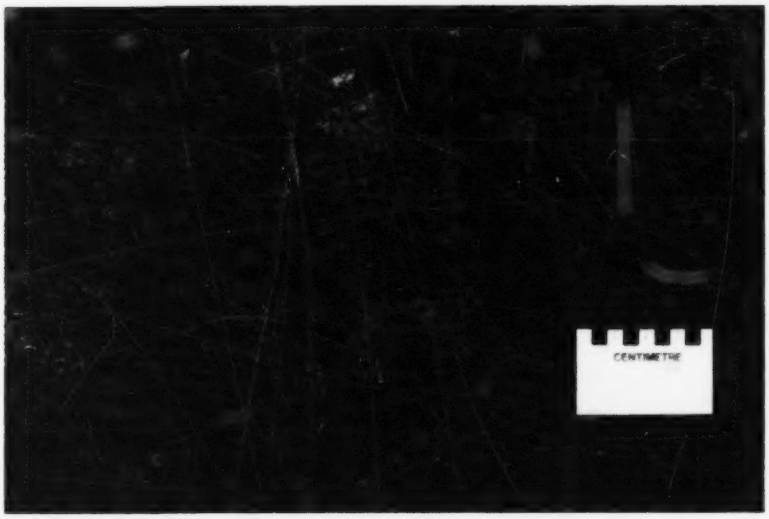


Figure GS-5-8: Epidosite alteration domains in aphyric pillowed basalt (unit 4a), islet in the centre of Alberts Lake.

Figure GS-5-9: Mafic debris flow (unit 4c) with angular to irregularly shaped blocks in a mafic matrix, southeast bay of Alberts Lake.



Felsic volcanic rocks (unit 5)

The central part of the Sourdough Bay Block east of Alberts Lake consists mainly of massive rhyolite (unit 5a) and related rhyolite breccia (unit 5c). This felsic volcanic terrane is flanked to the south by major gabbro and granodiorite intrusions (Kalliokoski, 1949) and appears to be in gradational contact with a tonalitic intrusion that extends east from Alberts Lake to Naosap Lake (Fig. GS-5-2). Rhyolite breccia at the east shore of Alberts Lake is transitional with massive rhyolite, which in turn is gradational with the tonalite immediately to the northeast.

Rhyolite and rhyolite breccia in the southeast part of Alberts Lake are intimately intercalated at a scale of 2 to 10 m. The massive felsic flows (unit 5a), which are subordinate to rhyolite breccia, are sparsely feldspar phyric and locally contain minor amygdules (quartz, epidote or chlorite). Differentially weathered flow lamination at a scale of 1 to 10 mm occurs in several units, whereas narrow (2–5 cm) concordant zones with spherulitic fabric are rare. Secondary epidosite domains occur in some felsic flows as sporadic ovoid pods (1–10 cm) with fine, exsolved quartz blebs.

Rhyolite breccia (unit 5c) is interpreted as autoclastic and is characterized by a chaotic, unsorted assemblage of rhyolite fragments that constitute up to 70% of the rock (Fig. GS-5-10). The breccia consists of predominantly small (0.5–10 cm), angular to irregular fragments and sporadic blocks up to 70 cm across (Fig. GS-5-11). The rock also contains sporadic, flow-laminated rhyolite lobes (up to 2 x 3 m) and elongate tongues that are locally flow folded, possibly due to the extrusion of massive rhyolite into unconsolidated hyaloclastic deposits. The majority of the clasts are finely flow-laminated at a scale of 1 to 3 mm; the laminar fabric is commonly warped or contorted due to contemporaneous flow during incorporation of the fragments and emplacement of the breccia. Massive, nonlaminated, white

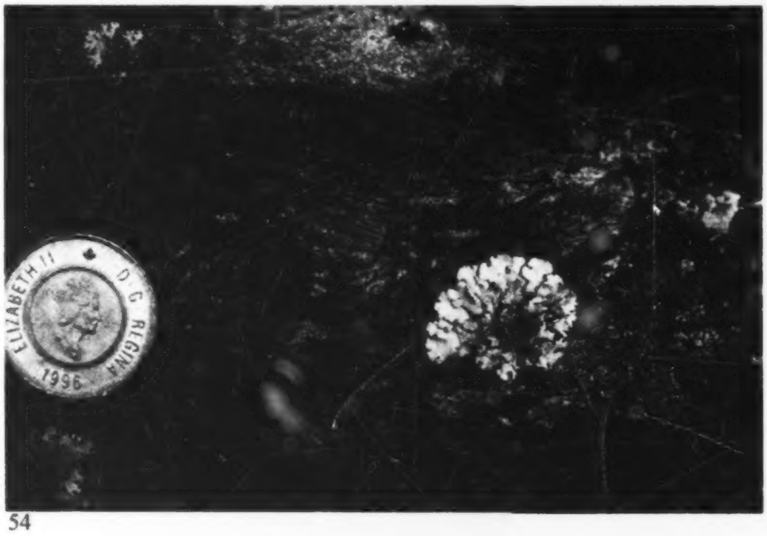


Figure GS-5-10: Rhyolite breccia (unit 5c) with flow-laminated, angular fragments, some of which are plastically deformed, southeast shore of Alberts Lake.

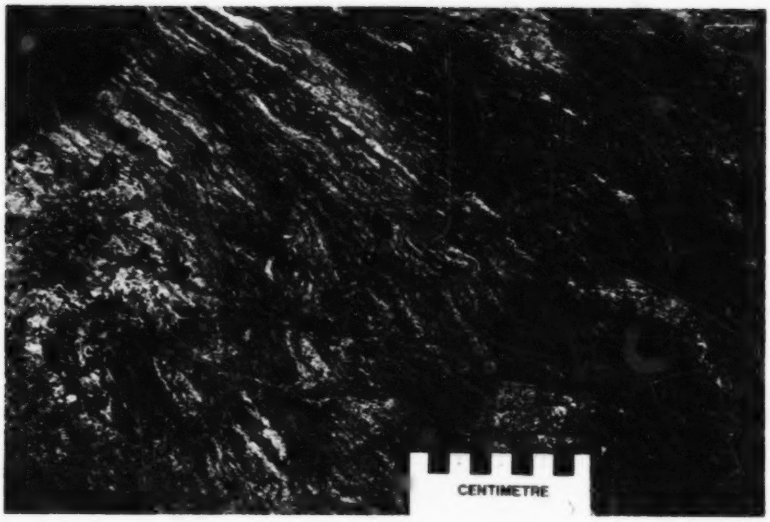


Figure GS-5-11: Flow-laminated rhyolite block in breccia (unit 5c), southeast shore of Alberts Lake.

rhyolite clasts account for less than 10% of the rock. The breccia is sparsely plagioclase (±quartz) phyric and locally contains pyritohedra and chloritized hornblende porphyroblasts. Finely pitted, weathered surfaces, attributed to secondary carbonatization, are common within the felsic volcanic unit.

Chert, cherty siltstone (unit 6b)

Laminated chert (unit 6b) is associated with sporadic mafic tuff units within the felsic volcanic terrane at southeastern Alberts Lake (see description of unit 4b). At one locality 1 km north of Christie's island, four thin (1–4 cm) chert beds within a mafic tuff unit are contorted and disrupted (Fig. GS-5-12), resulting in tabular rafts of sediment within the 3 m wide mafic tuff. The chert is characterized by fine (1–3 mm), white and dark grey laminae that are slightly magnetiferous. Along strike from the mafic tuff, a 15 m wide basaltic unit also contains sporadic white chert as tabular to irregularly shaped rafts (up to 0.8 m long and 4–25 cm thick) that are assumed to be derived from sedimentary layers. In addition, a 25 cm thick chert bed occurs at the contact between two flows (aphyric and plagioclase phyric, respectively) within the mafic volcanic unit. The chert is locally mineralized with up to 7% pyrite-chalcopyrite and associated malachite over a 10 cm wide zone. Similar mineralized chert also occurs at the contact between a basalt flow and a related mafic sill. The contacts between the mafic volcanic–chert formation and flanking felsic volcanic rocks at this locality have been intruded by several prominent felsic porphyry intrusions (unit 8b).

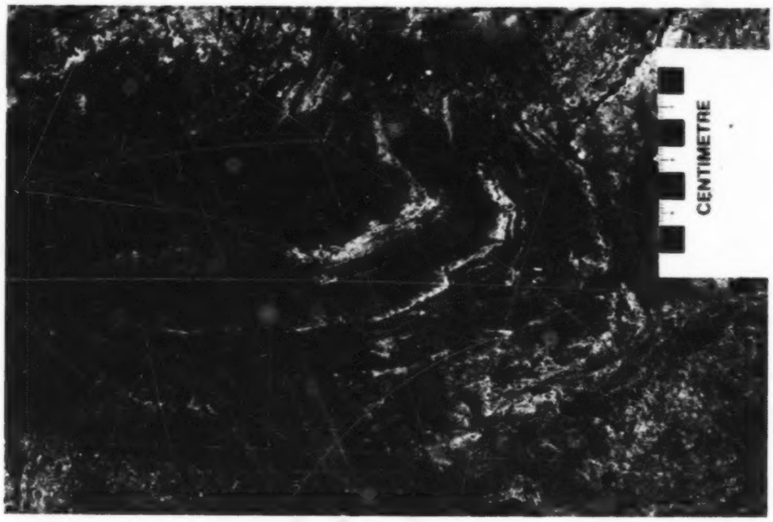


Figure GS-5-12: Laminated chert bed (unit 6b) within mafic tuff is folded and disrupted, 1 km north of Christie's island, Alberts Lake.

INTRUSIVE ROCKS

Intrusive rocks inferred as synvolcanic or penecontemporaneous with 1.88 Ga volcanism

Tonalite, leucotonalite, quartz diorite (unit 7a)

The granitoid terrane between Alberts and Naosap lakes (Fig. GS-5-2) consists of tonalite, granodiorite and related porphyritic phases. The granitoid rocks are not all coeval, but include both an early tonalitic phase, penecontemporaneous with volcanism at Alberts Lake, and later granitoid rocks that postdate the regional S_1 foliation at Naosap Lake (Kalliokoski, 1949; Gilbert, 1997). Kalliokoski (1949) mapped the central part of this terrane as "fine-grained granodiorite" and the peripheral zones as "quartz latite" (felsic porphyry). Only the northeast margin of this granitoid terrane (Gilbert, 1997) and the southwest part, east of Alberts Lake (Preliminary Map 2002-1), have been mapped by this author.

The southwest part of the granitoid terrane consists of fine- to medium-grained, massive tonalite to leucotonalite (unit 7a), characterized by hypidiomorphic (plagioclase) texture and 3 to 7% disseminated pyrite. The tonalite locally contains ragged chloritic aggregates (2–3 mm, 5–10% and locally 20% of the rock) and, toward the margin of the intrusion, the rock is finer grained and sparsely plagioclase±quartz phyric. The granitoid rocks are interpreted as penecontemporaneous with volcanism because they are lithologically gradational with massive, sparsely plagioclase-phyric rhyolite (unit 5a) that occurs immediately to the southwest. This rhyolite is locally characterized by irregular fracturing interpreted as a result of 'in situ' cooling and contains minor breccia zones; the predominantly massive felsic volcanic facies is transitional southward with the massive to fragmental rhyolite terrane (units 5a, 5c) at southeast Alberts Lake.

Plagioclase±quartz porphyry (unit 8b)

Felsic porphyry intrusions occur sporadically within both the Lac Aimée and Sourdough Bay fault blocks. These concordant to locally discordant intrusions range from 0.5 to 15 m in width, and include at least four distinct rock types, based on phenocryst size and content. Sparsely porphyritic intrusions with 3 to 15% plagioclase (±quartz) phenocrysts are lithologically akin and probably related to extrusive rhyolite units in both the Lac Aimée and Sourdough Bay blocks. Conspicuous quartz-plagioclase porphyry dikes that contain up to 20% quartz and 25% plagioclase phenocrysts (1–5 mm) are of uncertain origin; these rocks are possibly slightly younger than the sparsely porphyritic dikes and may represent one of the latest magmatic phases associated with the volcanism. Densely plagioclase-phyric felsic dikes in the northwest and west-central parts of Alberts Lake contain 30 to 60% plagioclase, but little or no quartz; these early intrusions predate the regional S_1 foliation and are truncated by later felsitic dikes. A fourth rock type that occurs only at the southeast shore of Alberts Lake is characterized by a fine- to medium-grained, subporphyritic (plagioclase) texture and contains evenly distributed, elongate basalt xenoliths (0.5–3 cm, 5–15% of the rock). All of the above porphyry phases are massive to moderately or strongly foliated and are considered to be penecontemporaneous with volcanism. In addition to the early porphyry types, postvolcanic felsic dikes locally truncate the regional (S_1) foliation; the younger dikes include both felsite and sparsely plagioclase±quartz–phyric porphyry.

Leucogabbro, anorthositic gabbro (unit 9d)

A roughly circular plug of quartz-bearing leucogabbro (unit 9d), approximately 700 m in diameter, occurs within the mafic volcanic section immediately north of Alberts Lake (Preliminary Map 2002-1). The intrusion, which contains 5 to 10% basalt xenoliths, consists of fine- to medium-grained leucogabbro that is massive to moderately foliated (S_1). The rock consists mainly of plagioclase and subordinate amphibole (up to 30%) and is characterized by hypidiomorphic plagioclase texture; intersertal quartz aggregates constitute up to 8% of the rock. The intrusion is interpreted as penecontemporaneous with volcanism, on the basis of the inferred pre-S_1 age and stratigraphic setting within the basaltic sequence; however, a younger age cannot be ruled out.

Diabase, porphyritic diabase (unit 9e)

Gabbro and diabase intrusions (unit 9e) that occur sporadically within the basaltic flows in the Lac Aimée Block include both aphyric and subordinate porphyritic types. Pyroxene-phyric diabase contains euhedral mafic phenocrysts (1–5 mm, 15–40% of the rock) altered to secondary amphibole. Plagioclase-phyric mafic units (phenocrysts 1–3 mm, 10–30% of the rock) up to 50 m thick are intercalated with aphyric basalt in the southwest part of the map area, close to the contact with gabbro (Fig. GS-5-2); the mafic units are interpreted as intrusive sills (unit 9e), but they may alternatively be extrusive and affiliated with unit 4.

Diabase dikes constitute 5 to 10% of the predominantly felsic volcanic terrane east of Alberts Lake, in the

Sourdough Bay Block. The massive to foliated dikes (unit 9e) are lithologically similar to diabase units within the Lac Aimée basalt. The mafic dikes east of Alberts Lake are typically 1 to 6 m wide and include both very fine grained types and less fine grained, distinctive 'sugary-textured' diabase. Fine thermal contraction fractures occur locally along dike margins. Ovoid hornblende amygdules or derived chloritic aggregates and epidote-filled amygdules along dike margins are characteristic of some intrusions. Elsewhere, the mafic dikes display laminated, pale to dark grey margins or zoning, characterized by aphyric margins and plagioclase-phyric cores. Minor diabase units (unit 9e) also occur within the tonalite (unit 7a) east of Alberts Lake.

Post–1.88 Ga intrusive rocks

Gabbro, amphibolite (10a)

Massive gabbro at the south margin of the map area contains two (or more) different phases that are distinguished on aeromagnetic maps (Heine, 1996). At the south shore of Alberts Lake, the intrusive rock is a homogeneous, mesocratic, subophitic gabbro. The contact with volcanic rocks northwest of the gabbro is marked by a topographic lineament that may locally be coincident with the Sourdough Bay Fault.

ECONOMIC GEOLOGY

Most occurrences of mineralization are either within strongly altered zones in basaltic flows or at contacts between mafic volcanic rocks and intrusive felsic porphyry or tonalite dikes. The west margin of the tonalite terrane east of Alberts Lake contains several iron-stained zones derived from pyritic mineralization along the shoreline, close to the inferred contact with basaltic flows (Preliminary Map 2002-1). The south end of the tonalite sill at the northwest shore of the lake is characterized by iron staining, pervasive carbonatization and quartz veining in a highly sheared zone at the contact with basalt. Sporadic occurrences of disseminated to stringer sulphide mineralization occur within aphyric and plagioclase-phyric basalt just north of the mafic volcanic–gabbro contact at southwestern Alberts Lake. One silicified flow contains ovoid pyrite-pyrrhotite aggregates (1 cm) with malachite rims. Extensive gossan development at the north end of an island in the west-central part of Alberts Lake is associated with sulphide mineralization in strongly silicified and epidotized basalt. Mineralization is sporadic over a 5 m wide zone within densely quartz-amygdaloidal basalt flows that contain subordinate volcanic breccia, felsic porphyry and quartz veins; disseminated pyrite-pyrrhotite and sulphide aggregates (up to 7%) occur in all rock types within the zone. Similar mineralization occurs in rhyolite breccia at the northeast corner of the island. Several occurrences of gold mineralization have been documented by Heine (1996) in quartz veins within the gabbro intrusion immediately south of the map area.

ACKNOWLEDGMENTS

Thanks are extended to Ryan Oger, who provided competent assistance with the field program. Al Bailes spent a day at Alberts Lake during the mapping and his constructive comments were much appreciated. Tim Corkery reviewed the manuscript and thanks are extended for this service.

REFERENCES

Ashton, K.E. 1993: Structure of the southern flank of the Kisseynew Gneiss Belt in Saskatchewan; *in* Trans-Hudson Orogen Transect, Report of Third Transect Meeting, Regina, Saskatchewan, April 1-2, 1993, LITHOPROBE Secretariat, Univerity of British Columba, LITHOPROBE Report No. 34, p. 84–87.

Bailes, A.H. and Syme, E.C. 1989: Geology of the Flin Flon–White Lake area; Manitoba Energy and Mines, Minerals Division, Geological Report GR 87-1, 313 p.

Bateman, J.D. and Harrison, J.M. 1945: Mikanagan Lake; Geological Survey of Canada, Map 832A, scale 1:63 360, with marginal notes.

Gale, G.H. and Dabek, L.B. 2002: Geology of the Baker Patton Complex, Flin Flon, Manitoba (parts of NTS areas 63K12, 13); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Geoscientific Map MAP2002-1.

Gilbert, H.P. 1986: Geological investigations in the Tartan Lake–Lac Aimée area; *in* Report of Activities 1986, Manitoba Energy and Mines, Minerals Division, p. 43–48.

Gilbert, H.P. 1996: Geology of the Lac Aimée–Naosap Lake area; *in* Report of Activities 1996, Manitoba Energy and Mines, Geological Services, p. 32–39.

Mines, Geological Services, p. 32–39.

Gilbert, H.P. 1997: Geology of the Lac Aimée–Naosap Lake area (NTS 63K/13SE and 63K/14SW); *in* Report of Activities, 1997, Manitoba Energy and Mines, Geological Services, p. 84–98.

Gilbert, H.P. 1999: Geochemistry of Paleoproterozoic volcanic rocks in the Lac Aimée–Naosap Lake area, Flin Flon Belt (parts of NTS 63K/13SE and 63K/14SW); Manitoba Energy and Mines, Geological Services, Open File Report OF99-1, 21 p.

Heine, T.H 1996: Geology of the Alberts Lake area; *in* Report of Activities, 1996, Manitoba Energy and Mines, Geological Services, p. 40–42.

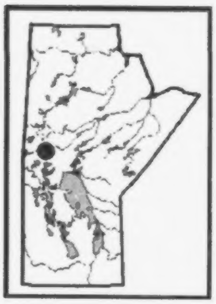
Kalliokoski, J. 1949: Weldon Bay; Geological Survey of Canada, Map 1020A, scale 1:63 360, with marginal notes.

Lucas, S.B., Stern, R.A., Syme, E.C., Reilly, B.A. and Thomas, D.J. 1996: Intraoceanic tectonics and the development of continental crust: 1.92–1.84 Ga evolution of the Flin Flon Belt, Canada; Geological Society of America Bulletin, v. 108, p. 602–629.

Syme, E.C. 1995: 1.9 Ga arc and ocean floor assemblages and their bounding structures in the central Flin Flon Belt; Trans-Hudson Orogen Transect, Report of Fifth Transect Meeting, Regina, Saskatchewan, April 3-4, 1995, LITHOPROBE Secretariat, University of British Columbia, LITHOPROBE Report No. 48, p. 261–272.

GS-6 RARE EARTH ELEMENT GEOCHEMISTRY OF SULPHIDE-BEARING STRATA IN THE FLIN FLON–SNOW LAKE AREA (NTS 63K), MANITOBA

by G.H. Gale



Gale, G.H. 2002: Rare earth element geochemistry of sulphide-bearing strata in the Flin Flon–Snow Lake area (NTS 63K), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 59-62.

SUMMARY

Geochemical studies of sulphide-bearing strata from two areas in the Paleoproterozoic Flin Flon Belt provide data on rare earth element (REE) profiles for barren sulphide strata. Of particular interest are analyses of apparently 'barren' strata from the Snow Lake area, which display positive Eu anomalies normally associated with volcanogenic massive sulphide (VMS) strata. This contrasts sharply with the negative Eu anomalies shown by the adjacent and barren sulphide strata of the 'Foot-Mud horizon' at Snow Lake. This example from the Snow Lake area illustrates the potential use of REE analyses in correlating strata and as a vector to mineralization.

INTRODUCTION

This project aims to evaluate the feasibility of discriminating between 'barren' and 'economic' sulphide strata using their rare earth element (REE) concentrations and pathfinder elements such as Ba, Au, Mo, Re, Sb and Eu. The goal is to determine if major- and trace-element data on sulphide strata may assist in 1) evaluating the source of matrix in sulphide-bearing strata, 2) discriminating Eu anomalies ascribed to alteration and lithological processes, and 3) establishing the presence of 'pathfinder' elements. A number of sulphide-bearing strata (sulphide facies iron formation or SFIF) from presumably 'barren strata' in the Flin Flon and Snow Lake areas were analyzed to determine their chemistry and to determine background rare earth element (REE) concentrations for comparison with those associated with VMS deposits.

FLIN FLON AREA

Location 1

Two samples were collected from rusty-weathered sulphidic strata exposed in an abandoned gravel pit (UTM Zone 14, 318050E, 6072200N, NAD 27) within 500 m of the eastern highway exit to Flin Flon. These samples contain 11% (Dunlop1) and 9% (Dunlop2) Fe_2O_3, approximately 60% SiO_2 and have an overall 'andesitic' composition. They contain less than 1.5% Na_2O_3 and greater than 2% K_2O. Both samples plot in the fields for altered rocks on the feldspar model diagram (Fig.GS-6-1) and the potassium alteration diagram (Fig. GS-6-2), indicating that they represent chemically modified volcanic rock compositions. Both samples have undergone similar alkali alteration, as the samples plot close together on both diagrams.

The essentially parallel REE profiles (Fig. GS-6-3) indicate different REE mass rather than different REE sources; the material responsible for the 'dilutant effects' (i.e., the difference in heavy REE contents) between the two samples is uncertain. The negative Eu profile for sample Dunlop2 is similar to REE plots of 'barren' sulphide mineralization from the 'Foot-Mud horizon' in the Snow Lake area and elsewhere (cf. Gale et al., 1997). However, the profile for sample Dunlop1 is similar to that of some unaltered mafic rocks and some distal exhalites. At this time, it is difficult to determine if this sample records the addition of Eu to a matrix that is similar to Dunlop2, or if it represents background values for volcanic rocks of this area.

Location 2

Samples WL1 to WL6 were collected sequentially, from west to east, along the south side of a roadcut on Highway 10, south of the White Lake mine; sample WL1 is from the westernmost sulphide-bearing strata and sample WL6 is from the easternmost strata. Sample WL6 is located at UTM Zone 14, 324520E, 60639950N, NAD 27 and sample WL1 is located approximately 40 m west of WL6.

Samples WL1 and WL3 plot in the field for unaltered rocks on Figures GS-6-1 and GS-6-2. The remaining samples exhibit minor total alkali alteration. The samples contain 11 to 20% Fe_2O_3 and 41 to 58% SiO_2, but do not exhibit any systematic compositional changes; for example, samples WL2 and WL 8 have 0.24 and 0.35% MnO, but 0.43 and 0.78% TiO_2, respectively.

The REE profiles for samples WL1, WL3, WL4 and WL6 (Fig. GS-6-3) are similar to those of unaltered rocks.

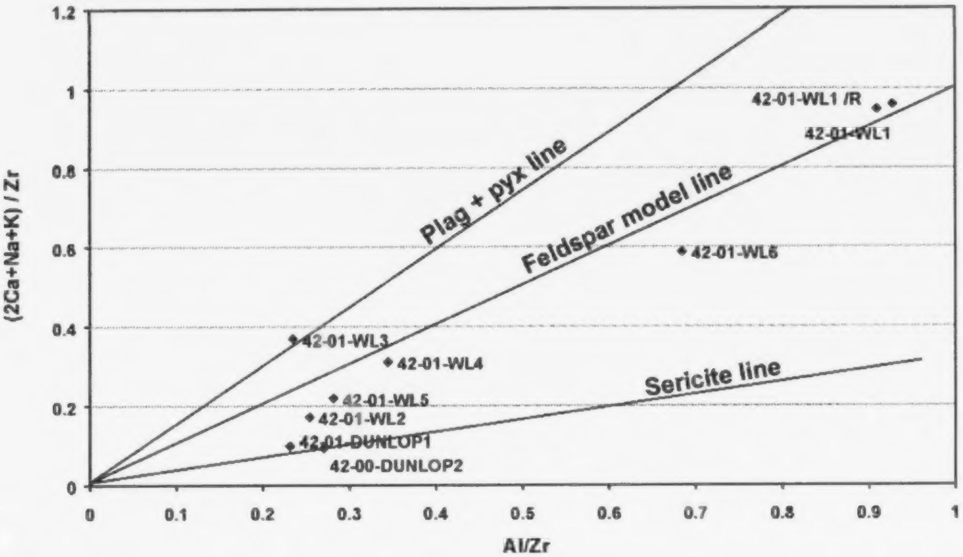


Figure GS-6-1: Feldspar model diagram (Madeisky and Stanley, 1993) for sulphide-bearing rocks, Flin Flon area. Altered rocks typically plot below the feldspar model line on this diagram.

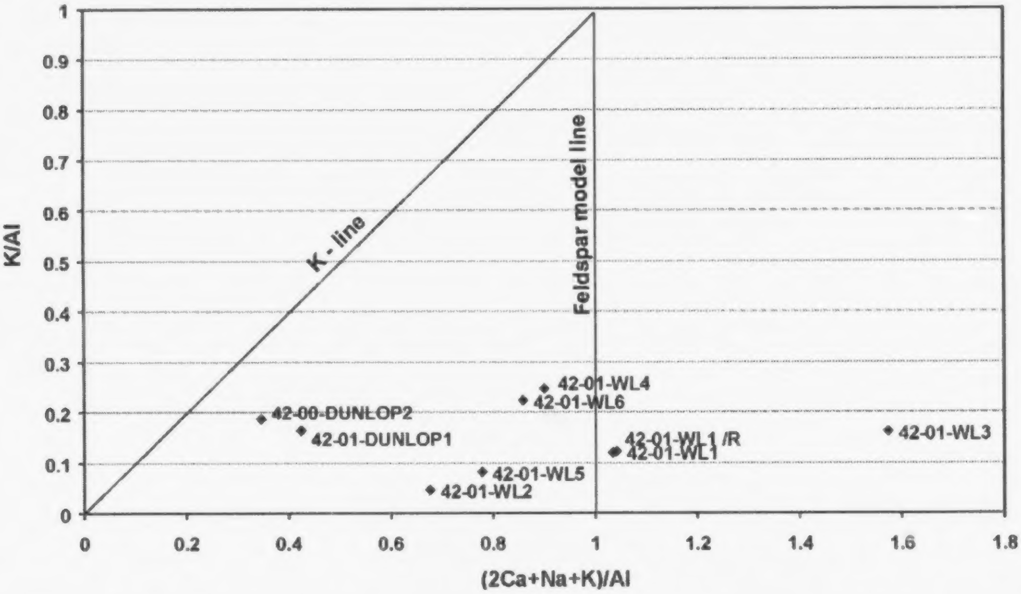


Figure GS-6-2: Potassium alteration diagram (Madeisky and Stanley, 1993) for sulphide-bearing rocks, Flin Flon area. Altered rocks typically plot to the left of the vertical line on this diagram.

The REE profiles for samples WL1, WL3, WL4 and WL6 (Fig. GS-6-3) are similar to those of unaltered rocks. However, the profiles for WL2 and WL5 differ considerably from the others, in that they have negative light REE slopes and flat to positive heavy REE slopes. This indicates either different protoliths for the clastic material or that other factors control the REE concentrations in these two rocks. These two rocks have marginally higher Fe_2O_3 than the other samples, but other element values plot within the range of the other four samples.

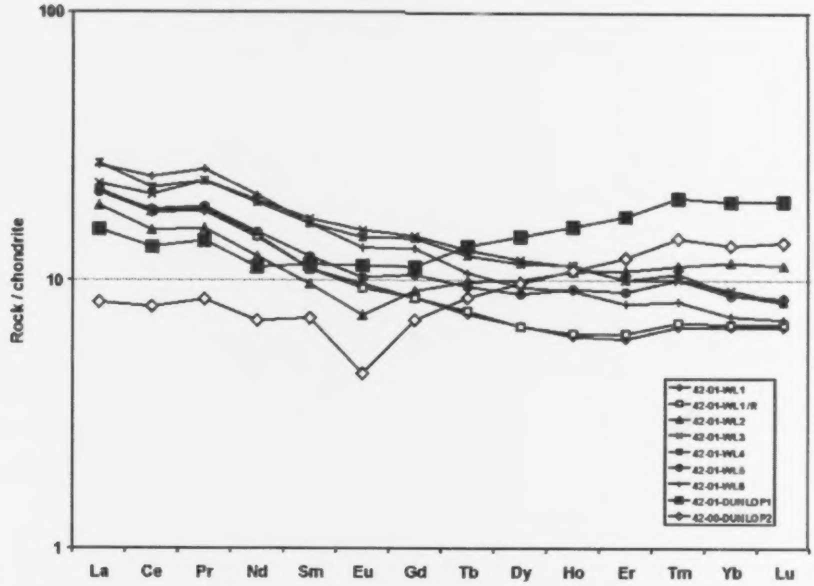


Figure GS-6-3: Rare earth element profiles for sulphide-bearing rocks, Flin Flon area.

SNOW LAKE AREA

Samples collected from two drillholes that intersected sulphide-bearing strata north and east of the Stall Lake mine have weak to moderately positive Eu anomalies (Fig. GS-6-4). These holes were drilled to test a geophysical conductor that appears to be the along-strike continuation of the 'Foot-Mud horizon' (Bailes and Galley, 1996). A sample from drillhole ROD31 with a weak positive Eu anomaly has minor sulphide (<15% Fe) and an overall mafic composition. This rock contains trace amounts of Pb (62 ppm), Ba (257 ppm), Cu (238 ppm), Zn (536 ppm), 2.9% Na_2O, 1.52% K_2O and 46% SiO_2, and does not appear to be altered. Three samples from drillhole ROD30, 100 m along

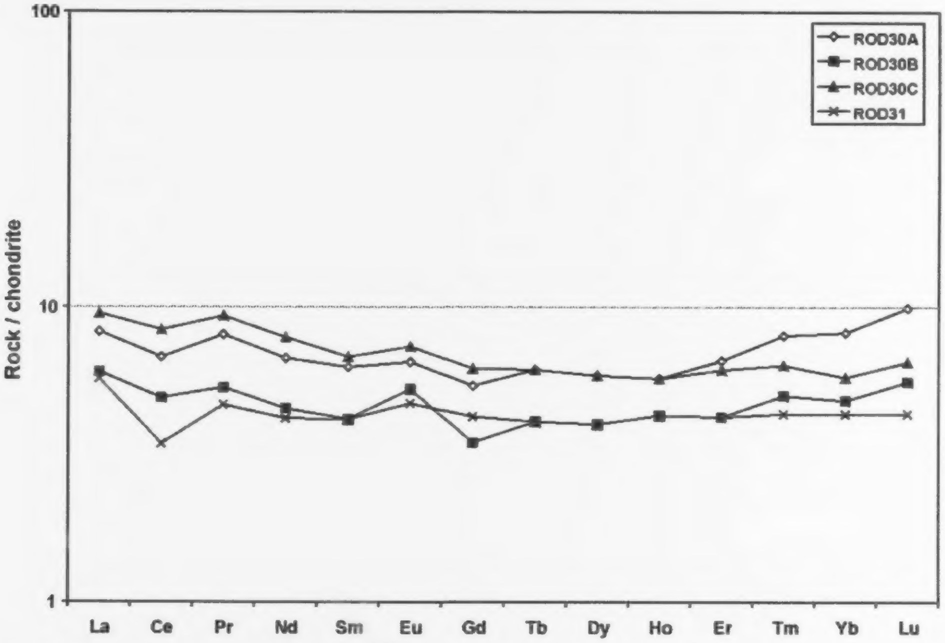


Figure GS-6-4: Rare earth element profiles for sulphide-bearing strata, Snow Lake.

strike from ROD31, have positive Eu anomalies. These rocks contain 12 to 35% Fe, 36 to 51% SiO_2 and 1.5 to 3.1% Na_2O_3, and have anomalous concentrations of Ba (99–400 ppm), Cu (280–620 ppm) and Zn (580–1800 ppm); similar Cu and Zn values occur in barren sulphide beds within the 'Foot-Mud horizon' (Gale et al., 1997).

These samples are unusual for the 'Foot-Mud horizon', in that they do not have the strong negative Eu anomaly characteristic of the 'Foot-Mud horizon' samples in other drill core (Gale et al., 1997). This indicates that the supposedly 'barren sulphide' conductor intersected in drill cores ROD31 and ROD30 may, in fact, be either a 'near-vent' phase of the barren 'Foot-Mud horizon' or an unrelated sulphide facies iron formation from a vent that could have been capable of producing a volcanogenic massive sulphide–type deposit. The geophysical conductors identifying the 'Foot-Mud horizon' and the sulphide strata intersected in drillholes ROD30 and ROD31 are separated by a nonconductive zone (G. Kitzler, pers. comm., 1999). Based on comparisons with other REE data (Gale et al., 1997), it appears that the sulphide sections intersected in drillholes ROD30 and ROD31 represent the distal portions of a VMS-type hydrothermal vent and warrant further exploration.

ACKNOWLEDGMENTS

Gerry Kitzler and Peter Dunlop are thanked for assistance in sample collection for this study. Peter Theyer kindly reviewed an early draft of the manuscript.

REFERENCES

Bailes, A.H. and Galley, A.G. 1996: Setting of Paleoproterozoic volcanic-hosted massive base metal sulphide deposits, Snow Lake; *in* EXTECH I: A Multidisciplinary Approach to Massive Sulphide Research in the Rusty Lake–Snow Lake Greenstone Belts, Manitoba, G.G. Bonham-Carter, A.G. Galley and G.E.M. Hall (ed.), Geological Survey of Canada, Bulletin 426, p. 105–138.

Gale, G.H., Dabek, L.B. and Fedikow, M.A.F. 1997: The application of rare earth element analyses in the exploration for volcanogenic massive sulfide type deposits; Exploration and Mining Geology, v. 6, no. 3, p. 233–252.

Madeisky, H.E. and Stanley, C.R. 1993: Lithogeochemical exploration for metasomatic zones associated with volcanic-hosted massive sulphide deposits using Pearce element ratio analysis; International Geology Review, v.35, no. 12, p.1121–1148.

GS-7

RARE EARTH GEOCHEMISTRY OF THE SNEATH LAKE MINERAL OCCURRENCE (NTS 63K16), MANITOBA

by G.H. Gale

Gale, G.H. 2002: Rare earth geochemistry of the Sneath Lake mineral occurrence (NTS 63K16), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 63–68.

SUMMARY

Examination of drill core from two holes drilled into an electromagnetic conductor at Sneath Lake indicates that the holes intersected different types of sulphide mineralization. Drillhole CMB-1 intersected layered solid sulphide and exhalite-bearing felsic sandstone. Drillhole CMB-2, located approximately 100 m along the strike of the same conductor, intersected sections of solid sulphide, but much of that sulphide is sheared. Within the sheared sulphides and associated biotite-chlorite schist are blocks of recrystallized earthy pyrite and a block of layered sphalerite-bearing, medium-grained pyrite derived from a solid sulphide lens of volcanogenic massive sulphide (VMS) type. Positive Eu anomalies are associated only with the exhalite-bearing rocks and layered zinc-bearing sulphide mineralization, whereas negative to flat Eu anomalies are associated with sheared mafic rocks and recrystallized earthy pyrite. The geochemical data illustrate the application of rare earth elements (REE) in the correlation of sulphide-bearing strata.

INTRODUCTION

The Sneath Lake property of Callinan Mines Ltd. is situated 10 km southwest of the volcanogenic massive sulphide deposits at Anderson Lake and 5 km southeast of those at Chisel Lake. The volcanic rocks at Sneath Lake are either at the same stratigraphic level as, or slightly below, those that host the Anderson mine (A.H. Bailes, pers. comm., 2002). A major fault separates the volcanic rocks from a younger, high-level felsic intrusion. Previous exploration in the Sneath Lake area included a number of holes drilled to investigate electromagnetic conductors.

Callinan Mines Ltd. optioned the property and conducted an electromagnetic survey that identified a previously untested conductor. This conductor, intersected by hole CMB-1 in 2000, was explained by a short section of near-solid pyrite with trace to minor metal values. The author analyzed a number of samples of the sulphides and silicate hostrocks as part of an ongoing program to test the use of REE data, specifically an increase in Eu relative to other REE, to vector VMS mineralization (Gale et al., 1997).

A positive Eu^d anomaly[1] was detected in the sulphides and silicic hostrocks adjacent to the sulphide intersection. This anomaly prompted the company to drill hole CMB-2 along the same conductor in 2001. Hole CMB-2 intersected near-solid sulphides, altered rocks and minor base-metal concentrations, but the sulphides are different than those intersected in drillhole CMB-1. This report documents the geochemistry of core and pulp samples and observations made on the drill cores, and shows how REE data can be used to establish that there are differences in origin of the sulphides in the two drillholes.

GEOLOGY

The Sneath Lake area is underlain predominantly by felsic volcanic rocks that range from aphyric to quartz-feldspar phyric with up to 15% phenocrysts. The area of interest is separated from the dominantly mafic volcanic rocks to the west by the Edwards Lake Fault; however, it appears from the geological maps (Fig. GS-7-1) that the felsic volcanic rocks continue westward on the west side of that fault (Bailes and Galley, 1992, 1996).

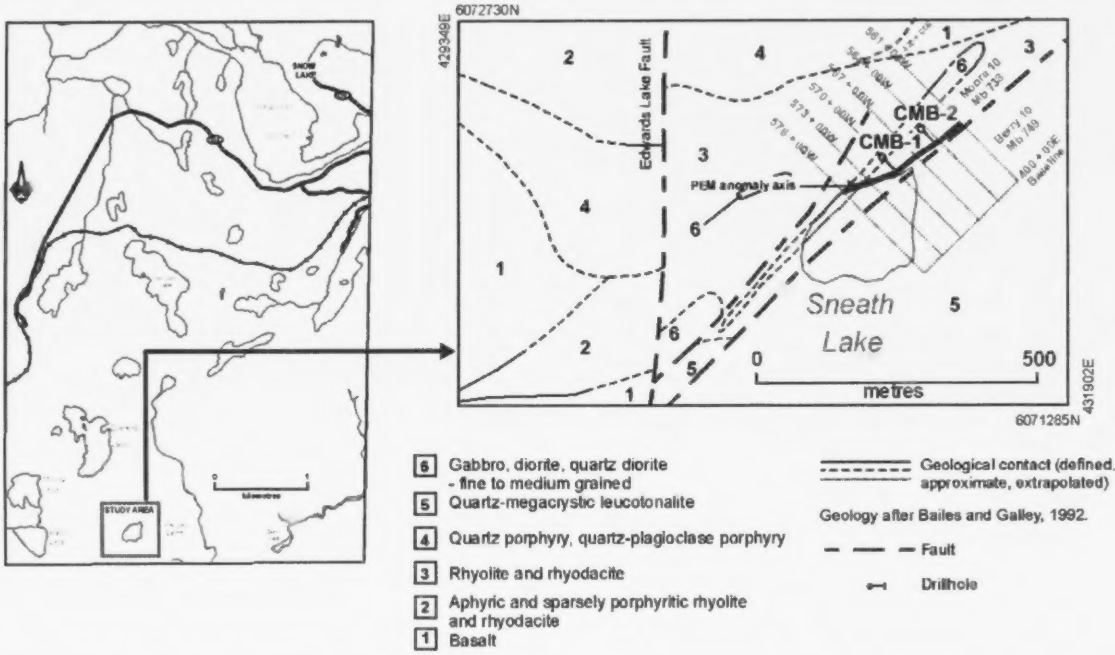
Mineralogical studies indicate that rocks west and north of Sneath Lake are locally intensely altered; these rocks include quartz-biotite-chlorite-garnet and amphibole-quartz±biotite±garnet±chlorite±sulphide mineral assemblages (Paradis et al., 1998). Several regional, east-striking faults and splays dissect the felsic rocks and may, to some extent, control the overall distribution of stratigraphic units.

MINERALIZATION

Disseminated sulphides are associated with some of the altered felsic rocks, and small areas of rusty-weathered rocks occur west of Sneath Lake. Solid sulphide, near-solid sulphide and sulphide-bearing chlorite-biotite schist are present in drill cores. The mineralization in the two drillholes, CMB-1 and CMB-2, is described and compared below.

---

[1] Eu^d = % deviation chondrite normalized Eu from Eu* (*see* Gale et al., 1997)


6072730N
429349E
Edwards Lake Fault
PEM anomaly axis
CMB-2
CMB-1
Moore 10
Mb 733
Berry 10
Mb 749
400 + 00E
Baseline
561 + 00W
564 + 00W
567 + 00W
570 + 00W
573 + 00W
576 + 00W
1
2
3
4
5
6
Sneath
Lake
0
500
metres
431902E
6071285N
STUDY AREA
6 Gabbro, diorite, quartz diorite - fine to medium grained
5 Quartz-megacrystic leucotonalite
4 Quartz porphyry, quartz-plagioclase porphyry
3 Rhyolite and rhyodacite
2 Aphyric and sparsely porphyritic rhyolite and rhyodacite
1 Basalt
Geological contact (defined, approximate, extrapolated)
Fault
Drillhole

Geology after Bailes and Galley, 1992.

Figure GS-7-1: Geological setting of the Sneath Lake occurrence.

Drillhole CMB-1

Drillhole CMB-1 intersected 25 cm of medium-grained, near-solid sulphide mineralization comprising 75 to 80% pyrite, 5 to 7% pyrrhotite and trace chalcopyrite and sphalerite. This is underlain by a 70 cm thick unit of quartz-rich rock containing 10 to 15% pyrrhotite, 5 to 7% pyrite, trace chalcopyrite and sphalerite and 1 to 3 mm biotiteporphyroblasts. Assays indicated maximum values of 0.10% Cu and 0.25% Zn over a 35 cm interval. This mineralization is hosted in 'altered rhyolite'.

Drillhole CMB-2

Drillhole CMB-2 intersected a 7.5 m thick zone of mineralized rocks that include biotite-chlorite schist, quartz-carbonate rock and near-solid sulphide. Assays indicated maximum concentrations of 0.10% Cu and 0.43% Zn in a 1.3 m section. This mineralization is hosted by felsic volcanic rocks and 'overlies' basalt.

The sulphide-bearing section contains:

4.6 m[2]	felsic volcanic rocks
62.6	quartz-biotite-sericite schist
63.2	coarse-grained pyrite and pyrrhotite, with coarse-grained biotite
63.7	75 to 90% pyrite, minor pyrrhotite and sphalerite; banded and/or layered
64.1	chlorite-biotite schist with sheared pyrite and pyrrhotite; includes coarse biotite books with pyrite pressure shadows
65.2	quartz-vein fragments in sheared sulphides and chlorite-biotite schist; late brittle deformation textures include pyrite-pyrrhotite veinlets around rock fragments

---

[2] start of core section (in metres)

67.2	solid sulphide: layered pyrite and minor sphalerite
68.3	earthy pyrite, fine grained, in a block with diffuse boundaries resulting from recrystallization of pyrite at block boundaries
68.4	grey-green quartz vein with sulphide mobilizate
68.5	solid sulphide, sheared
68.8	quartz vein
68.9	sheared biotite and chlorite with recrystallized and mobilized pyrite and pyrrhotite
69.6	earthy pyrite block
69.7	quartz vein and sheared volcanic rocks
69.8	(?)layered mafic rocks with biotite-rich sections.
70.1	basalt, (?)unaltered, foliated, biotite books in 'veins'
72.5	basalt; includes breccia and massive portions

Shear textures in the sulphides, biotite-chlorite schist and blocks of quartz-vein material all suggest that the sulphide-rich section in CMB-2 is part of a late brittle-ductile deformation zone. Thus, the CMB-2 sulphide-rich section has an origin that is quite different from the layered exhalite and sulphides intersected in drillhole CMB-1, even though the geophysical survey indicates that they form part of the same conductor.

GEOCHEMISTRY

Samples of hostrocks, exhalite and sulphide-bearing rocks were analyzed from drill cores CMB-1 and CMB-2 for major elements, trace elements and REE.

Samples from CMB-1

Samples of layered silicate rocks from CMB-1 plot on a feldspar model diagram (Fig. GS-7-2a) above the sericite line (slope 1/3), even though many of them contain chlorite as a mineral species; in altered rocks with chlorite as an alteration product, they should plot below the sericite line (Madeisky and Stanley, 1993). Addition of K and moderate depletion of Na and Ca are indicated by the potassium alteration diagram (Fig. GS-7-2b), where a number of the samples plot to the left of the vertical line, which separates altered rocks on the left from unaltered rocks on the right. Therefore, the silicate rocks are not the products of intense footwall hydrothermal alteration, and probably represent a mixture of altered rocks and exhalite. The K-metasomatism indicated by Figure GS-7-2b may be an indication of either the outer margins of a VMS alteration zone or K-rich exhalite. The widely different Al/Zr ratios (Fig. GS-7-2a) indicate that the silicate rocks and the silicate matrices to the sulphide-bearing rocks have more than one protolith. In addition, samples with Al/Zr ratios that plot well outside the fields for felsic and mafic volcanic rocks on Figure GS-7-2a appear, on visual examination, to be chemical sedimentary rocks.

Samples from CMB-2

Samples from CMB-2 contain intensely altered K-rich rocks with moderate Na and Ca depletion and plot close to the line with a slope of 1 (Fig. GS-7-2a). These chlorite-rich rocks plot close to the sericite line on Figure GS-7-2b, but do not appear to have undergone addition of Mg during alteration. The two samples that are relatively unaltered in alkali elements (i.e., plot to the right of the vertical line on the potassium alteration diagram in Fig. GS-7-2b) are sulphide-rich rocks with blocks of earthy pyrite. The wide range in Al/Zr ratios indicates that these rocks also do not have a common protolith.

The REE chemistry for samples from CMB-2 is distinctly different than that for CMB-1 (Fig. GS-7-3), in that the

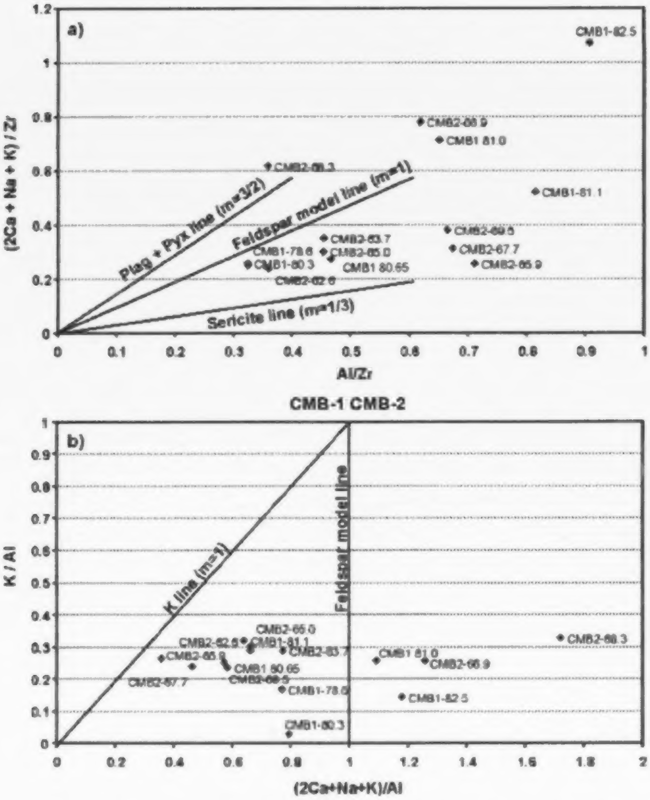


Figure GS-7-2: a) Feldspar model diagram for samples from Sneath Lake drill core. Unaltered felsic rocks generally plot along the feldspar model line on this diagram and basaltic rocks plot between the feldspar model line and the plag+cpx line. b) Potassium alteration diagram for samples from the Sneath Lake drill core. Unaltered rocks normally plot to the right of the vertical line on this diagram and mafic rocks plot well to the right, whereas rhyolite plots along or close to the vertical line.

silicate rocks do not have positive Eu^d values. The one sample from CMB-2 (CMB2-63.7) with a distinctive positive Eu^d anomaly is a sample of layered, near-solid sulphides typical of the layered sulphide lenses in VMS deposits. Three other sulphide-rich samples (CMB2-65.0, -65.9 and -66.9) with weakly negative to near-zero Eu^d values are a mixture of different types of sulphides in the shear zone and contain blocks of earthy pyrite, recrystallized earthy pyrite, pyrite-pyrrhotite-chalcopyrite mobilizate and (?)layered sulphide. The differences in their Eu^d values from that of sample CMB2-63.7 is a reflection of the different type of sulphide present in the samples.

The REE geochemistry is consistent with observations on other sulphide deposits, in that the sample with blocks of exhalite-derived layered sulphides has a definite positive Eu^d anomaly, whereas samples with earthy pyrite and sulphide mobilizate do not show this anomaly. In general, earthy pyrite has negative Eu^d values and sulphide mobilizate has weakly negative to near-zero Eu^d values. The REE data also suggest that the chlorite-biotite schist in CMB-2 represents sheared basalt because it does not have the strong negative Eu^d values of chlorite schist in the footwall alteration zones of VMS deposits.

CONCLUSIONS

Both the major-element and the REE data confirm differences between the sulphides and the immediate hostrocks intersected in drillholes CMB-1 and CMB-2, and substantiate the visual observations that these are not parts of a single contiguous sulphide lens, even though they appear to be part of the same conductor. This illustrates one of the uses of REE data in correlating metalliferous strata.

Drillhole CMB-1 intersected metal-poor, solid sulphides associated with chemical and clastic sedimentary rocks

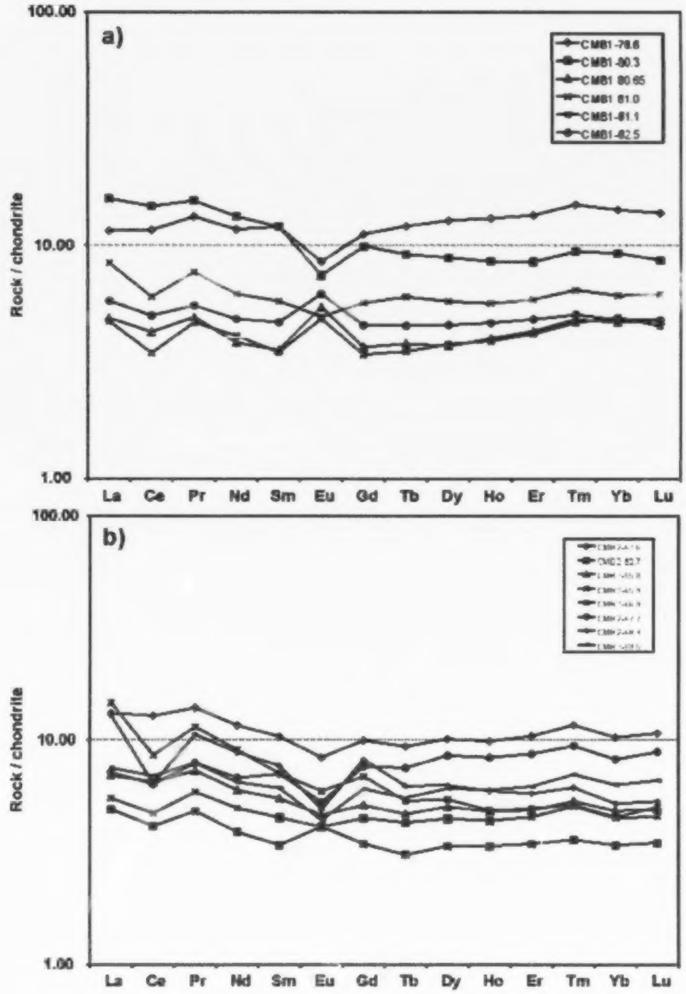


Figure GS-7-3: REE profiles for samples from drill cores CMB-1 (GS-7-3a) and CMB-2 (GS-7-3b).

derived, in part, from a VMS-type hydrothermal vent. These rocks are characterized by the presence of layered pyrite, alkali alteration and Eu^d >0 in the associated sedimentary rocks. Drillhole CMB-2, drilled along the same conductor, intersected sheared sulphides that included blocks of layered VMS-type sulphides, as indicated by the layered sphalerite-bearing sulphides and the presence of Eu^d >0 in the sample with sphalerite. The chlorite-biotite–rich rocks in the shear zone contain stringers of sulphides mobilized partly from earthy pyrite and partly from a source that included material from a VMS-type sulphide lens. The chemistry of the chlorite-bearing samples suggests that they are not the intensely altered and magnesium-enriched rocks commonly found in the immediate footwall of VMS deposits.

The blocks of sphalerite-bearing, near-solid sulphide in CMB-2 have been sheared from an undiscovered metal-rich sulphide body. In addition, the presence of Eu^d >0 values in some of the sulphides and exhalites indicate that the hydrothermal fluids were sufficiently hot and low in pH to form metal-rich VMS deposits. Further exploration should focus on the geology and geochemistry of the hostrocks, in order to establish viable drill targets.

ACKNOWLEDGMENTS

The author appreciates the support provided by Mike Muzylowski and Patrick DeVeaux in providing samples from this property. Peter Theyer and Alan Bailes kindly reviewed an early version of the manuscript.

REFERENCES

Bailes, A.H. and Galley, A.G. 1992: Anderson Lake (south) (parts of NTS 63K/16SE and 63J/13SW); Manitoba Energy and Mine, Preliminary Geological Map 1991S-2, scale 1:5 000.

Bailes, A.H. and Galley, A.G. 1996: Setting of Paleoproterozoic volcanic-hosted massive base metal sulphide deposits, Snow Lake; *in* EXTECH I: A Multidisciplinary Approach to Massive Sulphide Research in the Rusty Lake–Snow Lake Greenstone Belts, Manitoba, G.F. Bonham-Carter, A.G. Galley and G.E.M. Hall (ed.), Geological Survey of Canada, Bulletin 426, p. 105–138.

Gale, G.H., Dabek, L.B. and Fedikow, M.A.F. 1997: The application of rare earth element analyses in the exploration for volcanogenic massive sulfide type deposits; Exploration and Mining Geology, v. 6, no. 3, p. 233–252.

Madeisky, H.E. and Stanley, C.R. 1993: Lithogeochemical exploration for metasomatic zones associated with volcanic-hosted massive sulphide deposits using Pearce element ratio analysis; International Geology Review, v. 35, no. 12, p. 1121–1148.

Paradis, S., Bailes, A., Galley, A. and Shaw, K. 1998: Large-scale hydrothermal alteration systems, Snow Lake area, Manitoba, Canada; unpublished report, in Project 94E07, Third Annual Report, CAMIRO, Exploration Division, p. 281–332.

GS-8 VECTORING VOLCANOGENIC MASSIVE SULPHIDE MINERALIZATION AT THE RAINDROP ZONE, SNOW LAKE (NTS 63K16), MANITOBA

by G.H. Gale

Gale, G.H. 2002: Vectoring volcanogenic massive sulphide mineralization at the Raindrop zone, Snow Lake (NTS 63K16), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 69-74.

SUMMARY

Geochemical investigation of drill core from the Raindrop massive sulphide deposit indicates that the hydrothermal fluids may have vented at a stratigraphic level different from that targeted by early drill programs. Samples of volcanosedimentary rocks, including exhalite, exhibit a change in Eu content, from weakly negative to moderately positive, from south to north along the strata. These data suggest the presence of a hydrothermal vent site within a unit of volcanosedimentary rocks north of the previous drill target. Some of the problems encountered in using this approach in exploration are illustrated with samples from a drill-core section of mafic tuffaceous rock.

INTRODUCTION

The Raindrop zone is a small body of sulphide mineralization located approximately 1 km south of Daly Lake in the Snow Lake area (Fig. GS-8-1). The mineralization, discovered during drilling of an electromagnetic anomaly, underlies a swamp. It appears that the mineralized zone is hosted by felsic volcanic rocks of the Daly Lake rhyolite (Hodges and Manojlvic, 1993; Bailes and Galley, 1996; Paradis et al., 1998), because plots of drillholes indicate that the drill target was within rhyolitic rocks. A recent drill program to test the main sulphide lens intersected vein-type mineralization. Core samples were collected from the earlier drill programs to test the feasibility of using rare earth element (REE) data as a vector to sulphide mineralization.

This report summarizes results of geochemical studies on drill core from the property, and illustrates some of the problems that may be encountered in using this methodology.

GEOLOGICAL SETTING

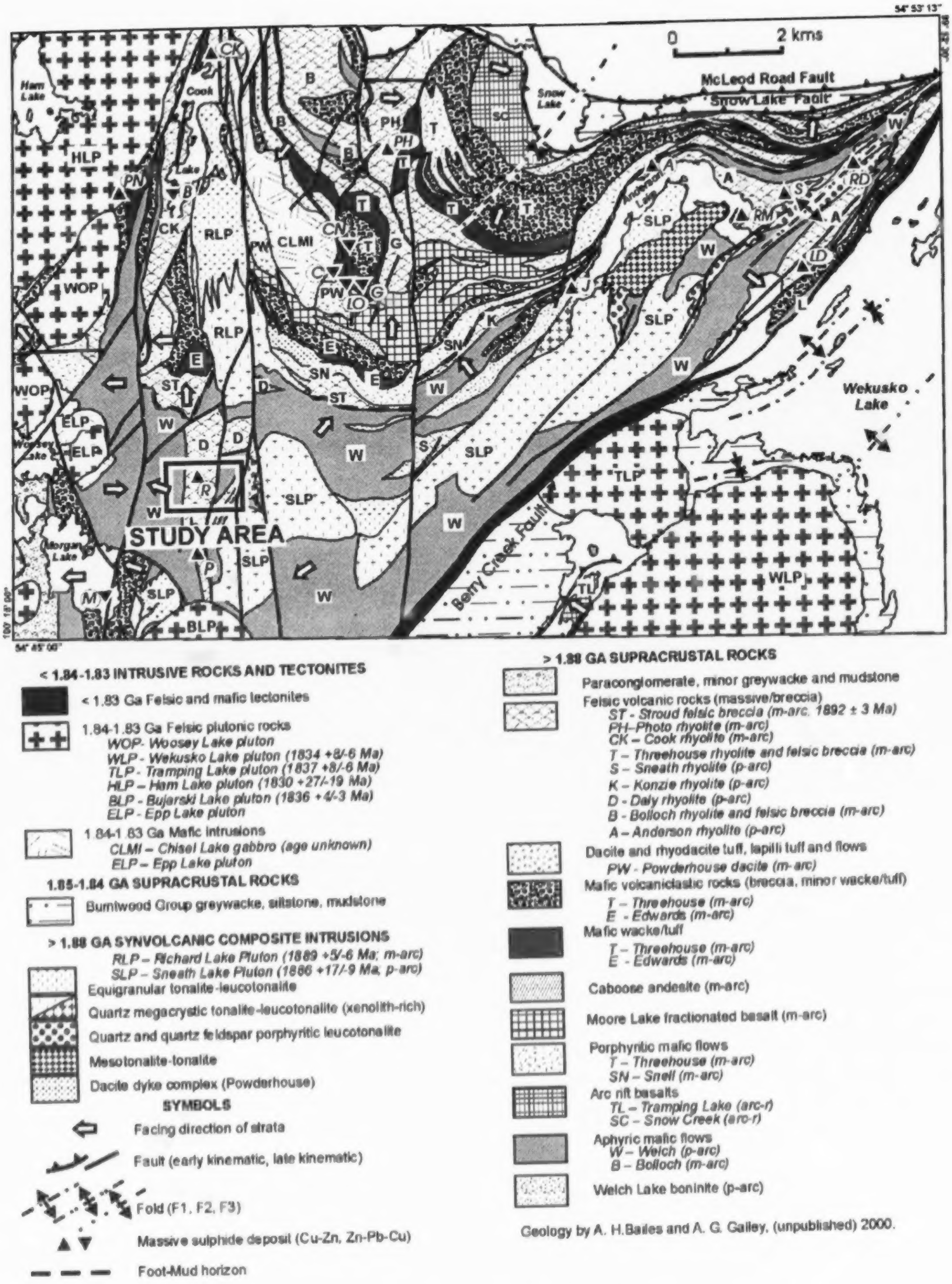
In the vicinity of the mineralization, the Daly Lake rhyolite consists predominantly of aphyric flows, with minor quartz-rich rhyolitic rocks of probable tuffaceous origin at the top of the felsic volcanic sequence. The rhyolitic rocks are overlain by a thin unit of layered mafic, intermediate and felsic volcanosedimentary rocks (the sulphide facies iron formation (SFIF) unit, Fig. GS-8-2) that locally contains layered sulphides, sulphide-bearing siltstone and quartz-sericite schist that, in part, resemble exhalite. This distinctive unit thins from over 30 m in drillhole C104 to approximately 1 m in drillhole C37. It has not been possible to confirm its continuity at depth, because it was not intersected in the only available drill core (C126).

A late mafic intrusion (diorite) cuts through the volcanic sequence. Company drill logs and surface maps indicate that the sedimentary rocks are present along strike as rafts within the intrusion. This indicates that the intrusion stoped into the volcanic pile and probably did not displace local strata any great distance; consequently, any sulphide deposits formed from a hydrothermal system in this area should not have been removed by the intrusion.

MINERALIZATION

The massive sulphide lens intersected in early drillholes consists of near-solid and solid pyrite and pyrrhotite, with minor sphalerite and chalcopyrite. In the cores examined to date, the individual sulphide minerals occur as stringers and blebs within each other, and there is no evidence of layered sulphides. The textures and distribution of the sulphides indicates that the mineralization has probably been mobilized into a zone of deformation. This interpretation is consistent with the presence of garnet-chlorite-sericite alteration on both sides of a solid sulphide lens (i.e., the alteration continues into the hanging wall, as illustrated on Fig. GS-8-2). Consequently, the logical position for exhalation of the hydrothermal vent associated with this alteration zone is at the top of the rhyolitic rocks during deposition of the volcanosedimentary SFIF unit (Fig. GS-8-2).

Pyrite-bearing intermediate to mafic rocks in drillhole C126 were interpreted to be the stratigraphic equivalent of the sedimentary rocks intersected in the upper portion of drillhole C114. However, the former are indistinctly layered, mafic tuffaceous rocks and are vastly different from the well-layered sedimentary rocks. In addition, a fault at the contact between altered rhyolite and the tuffaceous mafic rocks in C126 probably accounts for the abundant veins and veinlets of mobilized sulphides in the mafic tuffaceous rocks. This illustrates one the problems commonly encountered



54° 53' 13"
0
2 kms
McLeod Road Fault
Snow Lake Fault
Snow Lake
Ham Lake
Cook Lake
HLP
PN
CK
B
PH
T
SC
A
S
RD
RM
SLP
W
ID
CN
CLMI
RLP
WOP
C
PW
IO
G
J
K
L
SN
E
ST
D
WOP
ELP
Woosey Lake
R
STUDY AREA
Wekusko Lake
TLP
WLP
Berry Creek Fault
TL
Morgan Lake
M
P
BLP
100° 18' 00"
54° 45' 00"
< 1.84-1.83 INTRUSIVE ROCKS AND TECTONITES
< 1.83 Ga Felsic and mafic tectonites
1.84-1.83 Ga Felsic plutonic rocks
WOP- Woosey Lake pluton
WLP - Wekusko Lake pluton (1834 +8/-6 Ma)
TLP - Tramping Lake pluton (1837 +8/-6 Ma)
HLP – Ham Lake pluton (1830 +27/-19 Ma)
BLP - Bujarski Lake pluton (1836 +4/-3 Ma)
ELP - Epp Lake pluton
1.84-1.83 Ga Mafic intrusions
CLMI – Chisel Lake gabbro (age unknown)
ELP – Epp Lake pluton
1.85-1.84 GA SUPRACRUSTAL ROCKS
Burntwood Group greywacke, siltstone, mudstone
> 1.88 GA SYNVOLCANIC COMPOSITE INTRUSIONS
RLP – Richard Lake Pluton (1889 +5/-6 Ma; m-arc)
SLP – Sneath Lake Pluton (1886 +17/-9 Ma; p-arc)
Equigranular tonalite-leucotonalite
Quartz megacrystic tonalite-leucotonalite (xenolith-rich)
Quartz and quartz feldspar porphyritic leucotonalite
Mesotonalite-tonalite
Dacite dyke complex (Powderhouse)
SYMBOLS
Facing direction of strata
Fault (early kinematic, late kinematic)
Fold (F1, F2, F3)
Massive sulphide deposit (Cu-Zn, Zn-Pb-Cu)
Foot-Mud horizon
> 1.88 GA SUPRACRUSTAL ROCKS
Paraconglomerate, minor greywacke and mudstone
Felsic volcanic rocks (massive/breccia)
ST - Stroud felsic breccia (m-arc, 1892 ± 3 Ma)
PH–Photo rhyolite (m-arc)
CK – Cook rhyolite (m-arc)
T – Threehouse rhyolite and felsic breccia (m-arc)
S – Sneath rhyolite (p-arc)
K – Konzie rhyolite (p-arc)
D - Daly rhyolite (p-arc)
B - Bolloch rhyolite and felsic breccia (m-arc)
A – Anderson rhyolite (p-arc)
Dacite and rhyodacite tuff, lapilli tuff and flows
PW - Powderhouse dacite (m-arc)
Mafic volcaniclastic rocks (breccia, minor wacke/tuff)
T – Threehouse (m-arc)
E - Edwards (m-arc)
Mafic wacke/tuff
T – Threehouse (m-arc)
E - Edwards (m-arc)
Caboose andesite (m-arc)
Moore Lake fractionated basalt (m-arc)
Porphyritic mafic flows
T – Threehouse (m-arc)
SN – Snell (m-arc)
Arc rift basalts
TL – Tramping Lake (arc-r)
SC – Snow Creek (arc-r)
Aphyric mafic flows
W – Welch (p-arc)
B – Bolloch (m-arc)
Welch Lake boninite (p-arc)

Geology by A. H.Bailes and A. G. Galley, (unpublished) 2000.

Figure GS-8-1: General geology and location of the Daly Lake rhyolite and the Raindrop zone.

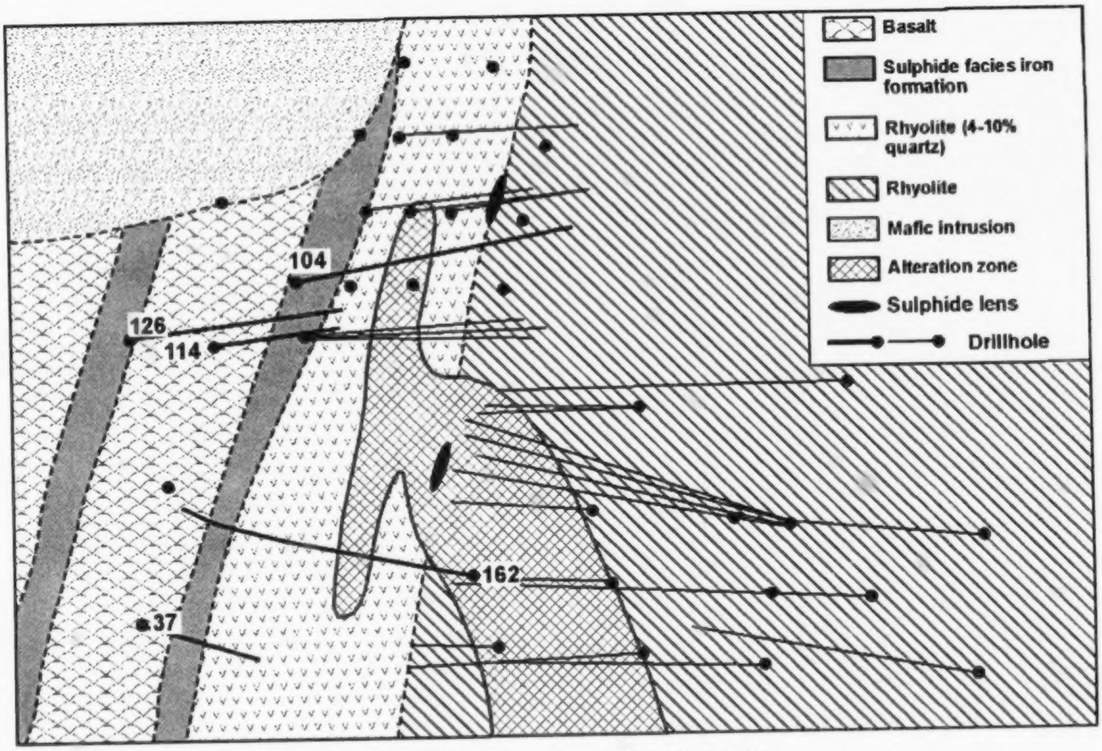


Figure GS-8-2: Geological setting of the Raindrop zone, with location of drillholes.

in correlation of mineralized units without the benefit of precise geochemical data.

GEOCHEMISTRY

Gale et al (1997) established REE patterns for exhalite, including layered sulphide ores, solid sulphides and footwall alteration zones in and around various volcanogenic massive sulphide (VMS) deposits, and proposed that REE data could be used to vector VMS mineralization. Rare earth element patterns typically associated with VMS mineralization are illustrated by samples from a small VMS deposit (Fig GS-8-3) within the same volcanic sequence, but several kilometres distal to the Raindrop zone.

In the absence of obvious exhalite in drill core near or adjacent to solid sulphide core sections at the Raindrop zone, selected samples of exhalite-like material from drillholes along the SFIF unit were analyzed. Positive Eu anomalies are present in several different beds within the unit. In addition, there is an apparent increase in the size of positive Eu anomalies along strike from south to north (Fig. GS-8-4). However, it cannot be established with certainty that the same beds were sampled in the different drillholes.

The Eu data indicate hydrothermal vent activity at a higher stratigraphic level than that targeted in the exploration programs to date. Furthermore, projection of the alteration zone, as defined on Figure GS-8-2, indicates that this zone of alteration should have vented at approximately the same position as that currently occupied by a mafic intrusion; this part of the strata has not been drilled.

Geochemical analyses of samples from drill core C126 illustrate some of the problems encountered in using Eu as a vector to VMS mineralization. Available drill logs for C126 indicate that the Eu-positive exhalite-bearing rocks analyzed in drill core C104 continued at depth and correlated with layered mafic (?)sedimentary rocks with abundant pyrite veinlets, near the bottom of the drillhole. Grab samples, over 1.5 m intervals, of these pyrite-bearing rocks indicate positive Eu anomalies in all samples (Fig. GS-8-5). However, major-element data and alteration indices show that these rocks are not altered and occupy the fields for unaltered basalt (Fig. GS-8-6). A re-evaluation of the drill core and the geochemical data indicates that the samples, which have only minor chemical variation from each other (Fig. GS-8-5), are probably unaltered mafic tuffaceous rocks; the positive Eu anomaly is consistent with those found in some unaltered basalt flows and mafic and felsic intrusions. This example illustrates one of the problems that may be

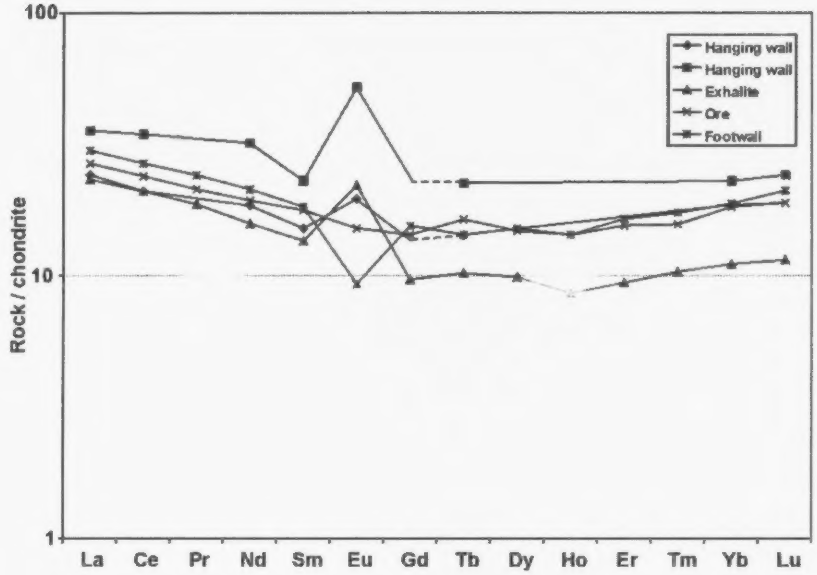


Figure GS-8-3: Rare earth element profiles for samples from the Spruce Point volcanogenic massive sulphide deposit, illustrating typical profiles for altered footwall rocks, solid sulphide, exhalite and associated hanging wall volcanosedimentary rocks.

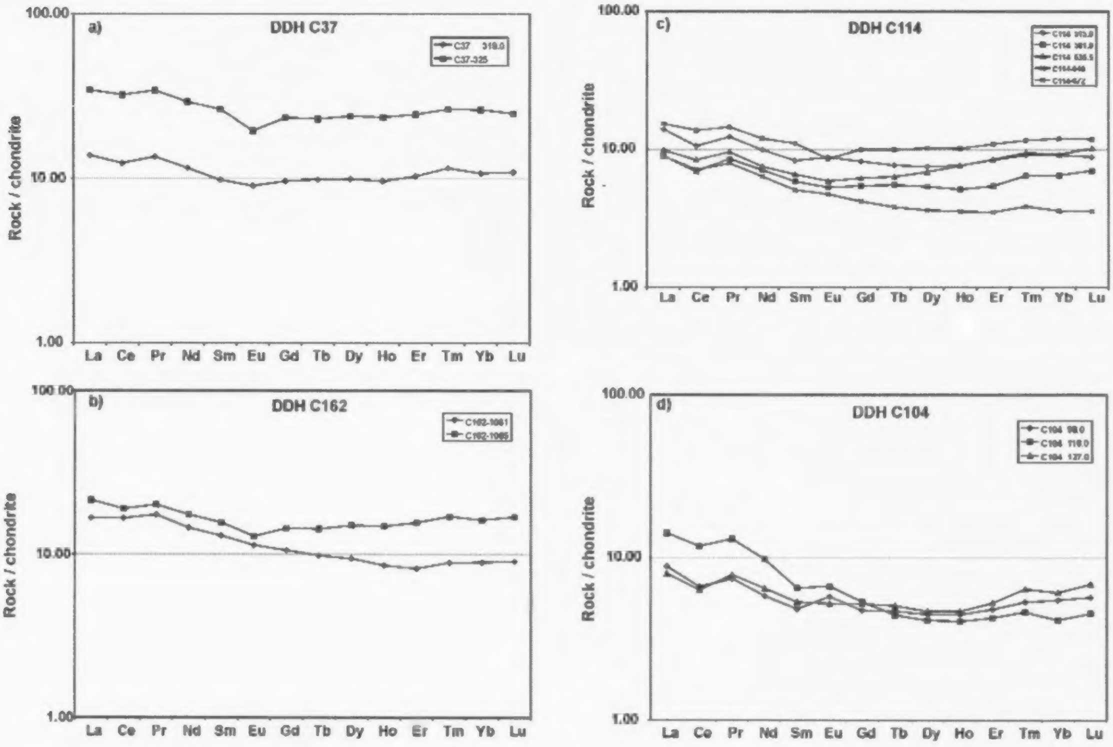


Figure GS-8-4: Rare earth element profiles for samples of sulphide facies iron formation in drill core along strike from the Raindrop zone. Location of drillholes shown on Figure GS-8-2.

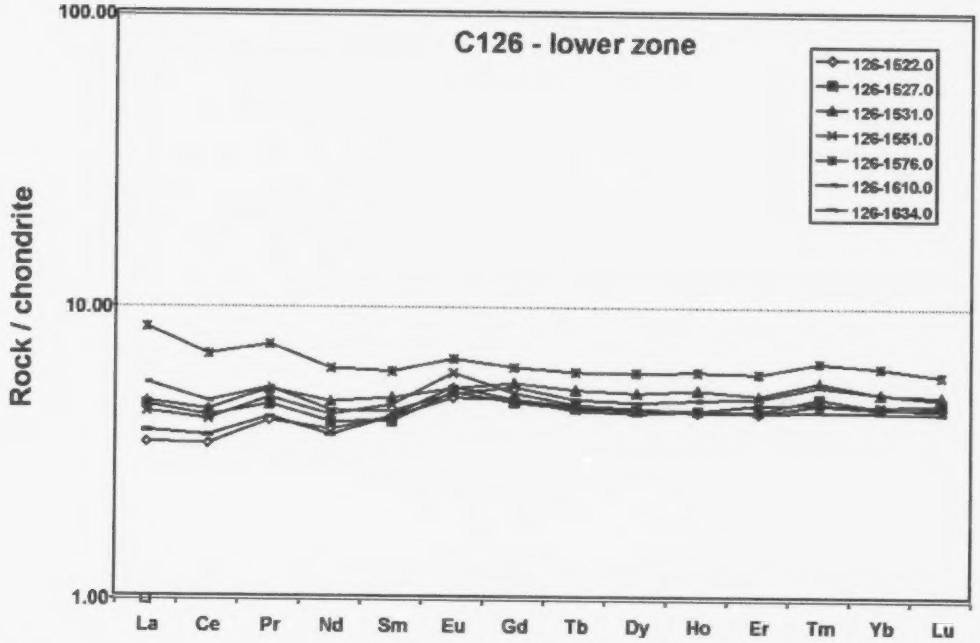


Figure GS-8-5: Rare earth element profiles for samples of pyrite-veined mafic tuffaceous rocks from drillhole C126, Raindrop zone.

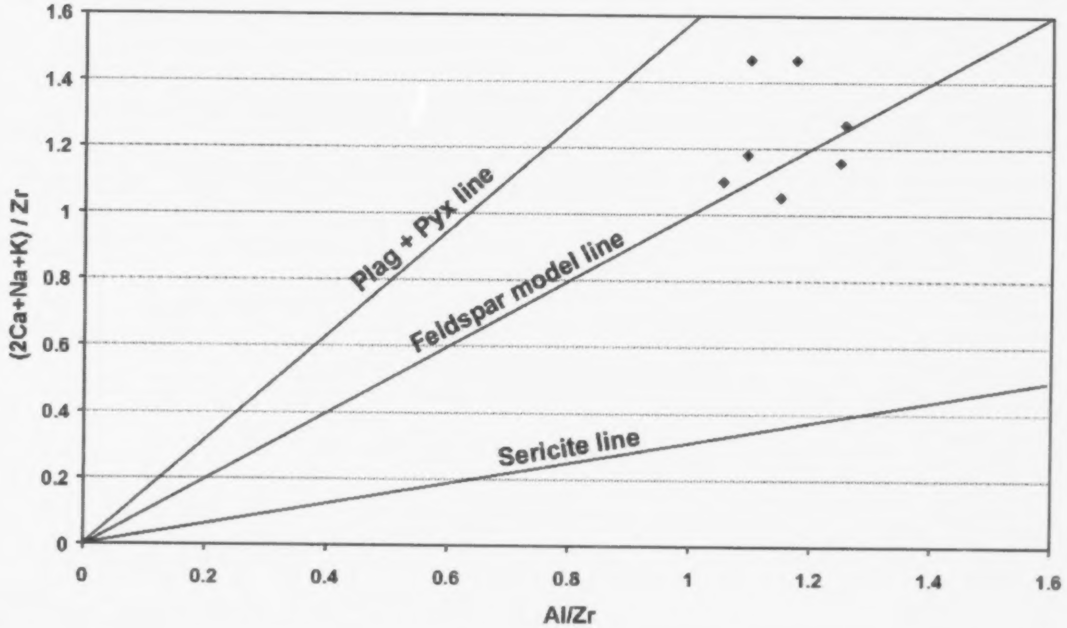


Figure GS-8-6: Feldspar model diagram (Madeisky and Stanley, 1993) for samples from drill core C126. Unaltered mafic rocks commonly plot between the plag+cpx and feldspar model lines.

encountered when using this methodology without due consideration of the stratigraphic position and primary geochemical attributes of the rocks under investigation.

ACKNOWLEDGMENTS

The writer is indebted to Patrick DeVeaux and Mike Muzylowski of Callinan Mines Ltd for provision of samples and access to drill cores. Gerry Kitzler kindly sampled drill core for the initial study. Scott Anderson kindly reviewed an early draft of the manuscript.

REFERENCES

Bailes, A.H. and Galley, A.G. 1996: Setting of Paleoproterozoic volcanic-hosted massive base metal sulphide deposits, Snow Lake; *in* EXTECH I: A Multidisciplinary Approach to Massive Sulphide Research in the Rusty Lake–Snow Lake Greenstone Belts, Manitoba, G.F. Bonham-Carter, A.G. Galley and G.E.M. Hall (ed.), Geological Survey of Canada, Bulletin 426, p. 105–138.

Gale, G.H., Dabek, L.B. and Fedikow, M.A.F. 1997: The application of rare earth element analyses in the exploration for volcanogenic massive sulfide type deposits; Exploration and Mining Geology, v. 6, no. 3, p. 233–252.

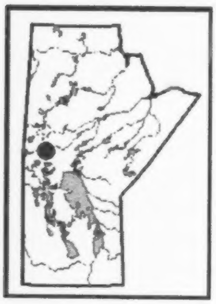
Hodges, D.J. and Manojlovic, P.M. 1993: Application of lithogeochemistry to exploration for deep VMS deposits in high grade metamorphic rocks, Snow Lake, Manitoba; Journal of Geochemical Exploration, v. 48, p. 201–224.

Madeisky, H.E. and Stanley, C.R. 1993: Lithogeochemical exploration for metasomatic zones associated with volcanic-hosted massive sulphide deposits using Pearce element ratio analysis; International Geology Review, v. 35, no. 12, p. 1121–1148.

Paradis, S., Bailes, A., Galley, A. and Shaw, K. 1998: Large-scale hydrothermal alteration systems, Snow Lake area, Manitoba, Canada; unpublished report, in Project 94E07, Third Annual Report, CAMIRO, Exploration Division, p. 281–332.

GS-9 GEOCHEMISTRY OF DRILLCORE SAMPLES, ALDERS, PEAT, BOG IRON AND TILL AT REED LAKE, MANITOBA (NTS 63K9)

by G.H. Gale



Gale, G.H. 2002: Geochemistry of drillcore samples, alders, peat, bog iron and till at Reed Lake, Manitoba (NTS 63K9); *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p.75–82.

SUMMARY

Two drillholes intersected conductive volcanosedimentary rocks, which probably represent distal exhalites from a hydrothermal vent, with positive Eu anomalies. A test survey of alder twigs in the vicinity of this zone of conductive rocks yielded several samples with anomalous Ba, Au, Mo, Re, Sb and Eu, but they did not outline the conductor. Samples of peat, bog iron and till were collected from a muskeg over the same area. Bog iron and till samples from this survey will be analyzed by selective extraction methods and reported later.

INTRODUCTION

Rock geochemical studies of drillcore from two drillholes at Reed Lake indicate that the area has the potential to contain massive sulphide deposits. Studies were initiated to determine if selective chemical extraction methods could be used to delineate geochemical anomalies in tills beneath lake bottom sediments and floating bog. Results from rare-earth element (REE) studies of sulphide-bearing rocks and ashed alders and metal contents of ashed alders are presented in this report.

BACKGROUND AND PURPOSE

Exploration of an electromagnetic anomaly under muskeg with drillhole R96-04, near the south shore of Reed Lake, in 1996 did not provide any geological explanation for the presence of a strong distinctive 1 km long conductor (Fig. GS-9-1). Examination of the drillcore by the author indicated that mostly intrusive rhyolite, which did not reveal

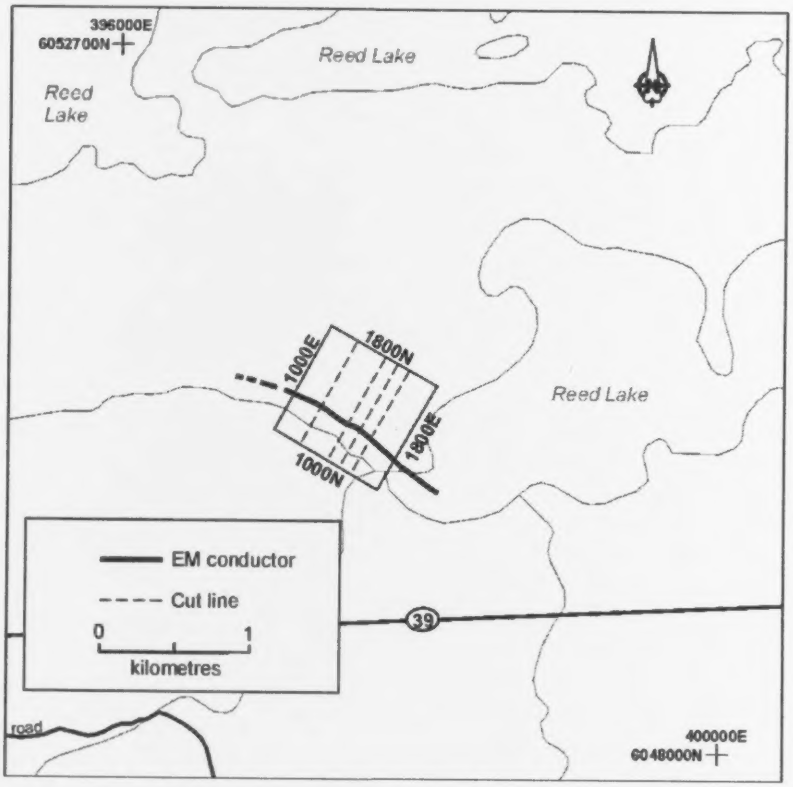


Figure GS-9-1: Location of the Reed property at Reed Lake.

significant alteration indices, had been sampled in a previous geochemical survey. This examination also revealed that felsic volcanic sandstones containing minor sulphides and blocks of altered rhyolite occur between aphanitic felsic dikes. The altered felsic volcanic sandstones were sampled during this study, with results reported below.

An initial geochemical survey of drillcore samples from hole R96-04 revealed both weakly altered rhyolite and felsic sandstone, with the latter displaying modest positive europium anomalies in several samples. Previous studies by Gale et al. (1997) have shown positive Eu anomalies to be commonly associated with exhalites and volcanogenic massive sulphide deposits. Drillhole CR-4, collared 100 m east of hole R96-04, intersected altered rhyolite, felsic volcanic sandstone, well-layered siltstones and layered barren pyrrhotite. Geochemical data on sample pulps and grab samples of drillcore indicate the presence of trace amounts of copper and zinc and positive Eu^d values in several samples of felsic sandstone. In addition, anomalous concentrations of other elements (Ba, As, Ag, Sn) in the volcanosedimentary rocks suggest the presence of distal exhalative hydrothermal vent activity at the stratigraphic level of the conductor.

The location of this conductor and the positive Eu^d anomalies obtained from the drillcore provide a unique opportunity to test the feasibility of using partial extraction methods in undisturbed surficial materials to determine if

- partial chemical extraction methods are useful exploration methods for tills underlying muskeg and floating muskeg;
- there are differences in the metal ion contents of material sampled beneath muskeg and material sampled beneath open water;
- Eu anomalies in rocks underlying bogs are reflected in the bog vegetation; and
- partial chemical extraction methods can be used to establish future drill targets along this conductor.

To test these concepts alder twigs were collected along two cut lines and cores of muskeg and Quaternary material were collected at five test sites. This report presents the methodology used in sampling the muskeg and some of the results obtained to date.

GEOLOGICAL SETTING

The Reed property is situated in a belt of felsic and mafic volcanic rocks that includes the past-producing Spruce Point mine (Fig. GS-9-1). In addition, other volcanogenic massive sulphide (VMS) type mineral occurrences have been intersected in the area (W.B. Dunlop, pers. comm., 2000). The electromagnetic conductor of interest on the Reed property is situated in an area that is covered by muskeg and water (Fig. GS-9-2), which extend for over 500 m away from the drill sites. The only geological information in the immediate vicinity is derived from drillholes R96-04 and CR-4.

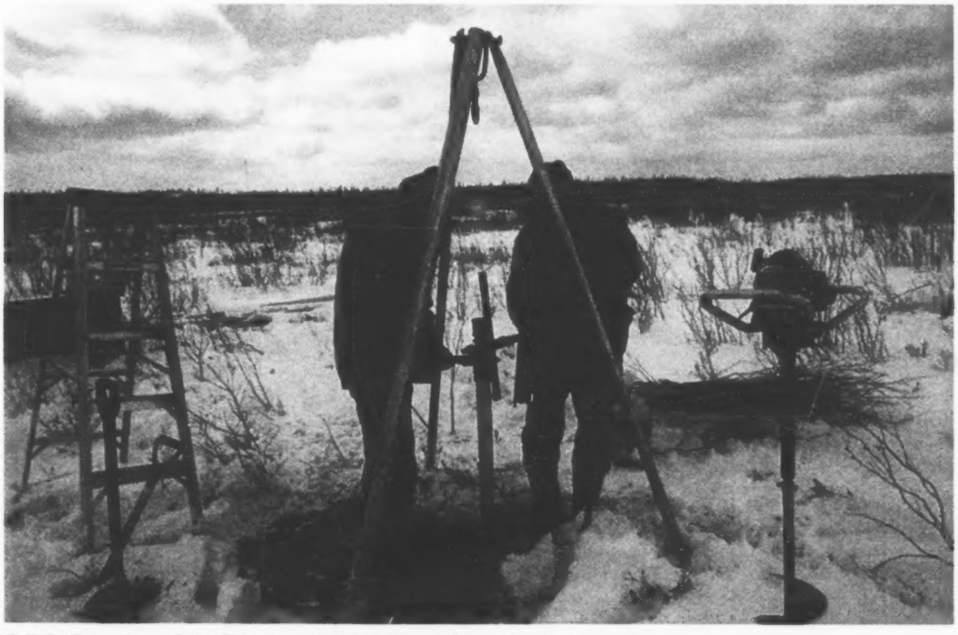


Figure GS-9-2: Overview of the Reed muskeg and sample equipment.

Figure GS-9-3 illustrates the geology of the drillcores. The conductive rocks are considered to occur within felsic volcanic rocks that structurally underlie mafic volcanic rocks of variable thickness. Felsic rocks in the uppermost half of drillhole R96-04 contain abundant 5 to 7 mm quartz crystals, with a bluish tinge, embedded in a fine-grained chloritic matrix. These rocks are tentatively interpreted as an intrusion. The massive and foliated mafic rocks are considered to be basalt flows and volcaniclastic rocks. The felsic rocks in the lowermost portions of the drillholes are dominantly fine-grained, in part quartz- and feldspar-bearing rocks derived from a felsic volcanic (rhyolitic) source. Definitive volcanic flow textures, such as flow breccia and flow bands, are not present. These massive to indistinctly

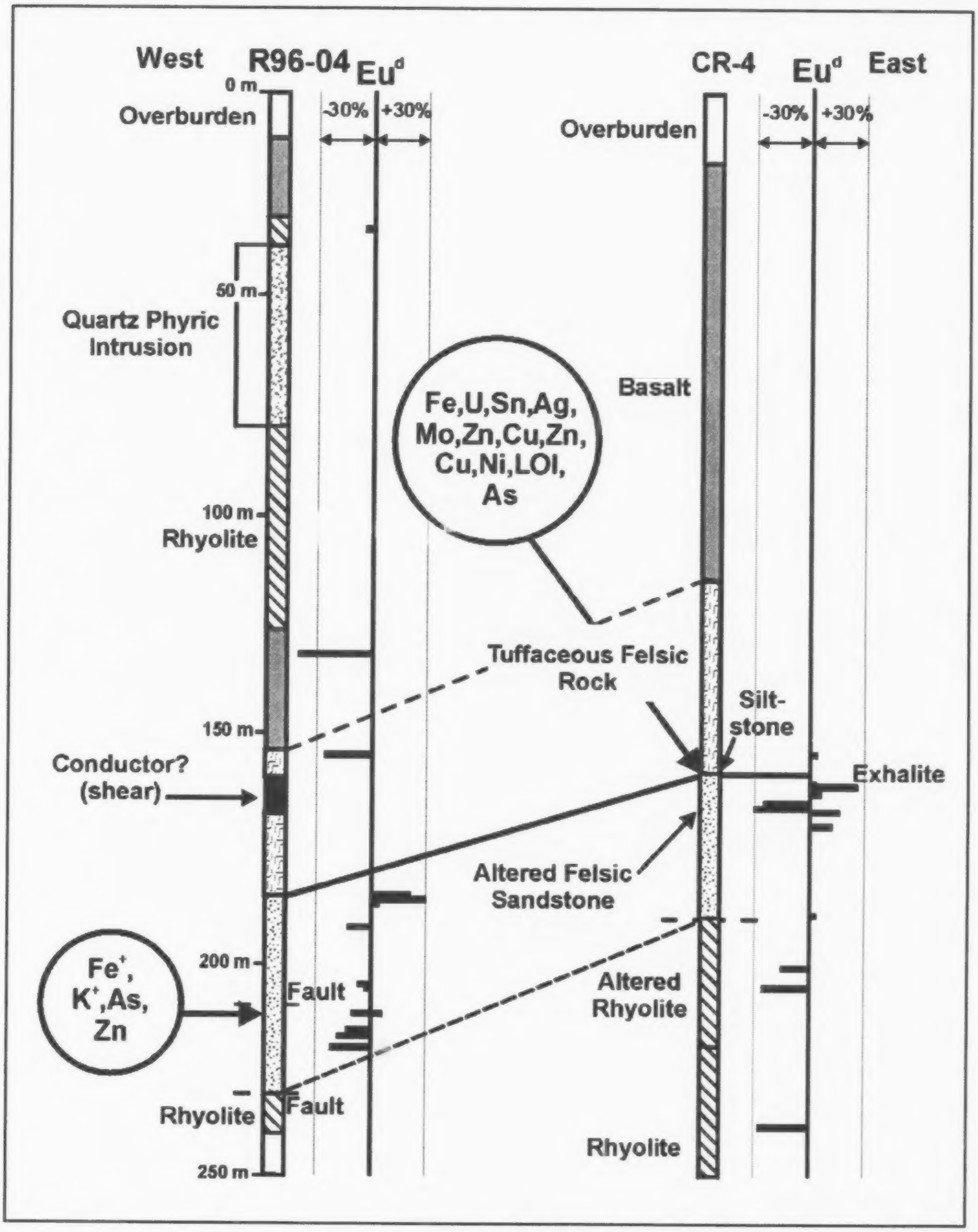

West
R96-04
Eu^d
0 m
Overburden
-30%
+30%
50 m
Quartz Phyric Intrusion
100 m
Rhyolite
150 m
Conductor? (shear)
200 m
Fe$^+$, K$^+$,As, Zn
Fault
Rhyolite
Fault
250 m
CR-4
Eu^d
East
Overburden
-30%
+30%
Fe,U,Sn,Ag, Mo,Zn,Cu,Zn, Cu,Ni,LOI, As
Basalt
Tuffaceous Felsic Rock
Silt-stone
Exhalite
Altered Felsic Sandstone
Altered Rhyolite
Rhyolite

Figure GS-9-3: Geology of drillholes R96-04 and CR-4. Multi-element anomalous zones are indicated in the inset circles.

banded felsic rocks are tentatively identified as predominantly felsic volcanosedimentary rocks (sandstones).

Well-layered siltstones, intersected in drillhole CR-4, are not present in drillhole R96-04. It is possible that these distinctive rocks have been cut out of the section by a zone of brittle-ductile deformation with a deformed quartz vein in drillhole R96-04; it is also possible that the clastic sedimentary rocks represent the margin of a depositional basin, near the top of the volcanic pile, that did not extend as far as R96-04. Altered rhyolite in drillhole CR-4 occurs below the sulphide-rich, unaltered siltstones; this suggests that the stratigraphic top is probably towards the south.

Geochemistry of Drillcore Samples

Analytical data from cores collected from the two drillholes are plotted in figures GS-9-4 to GS-9-8. On the TiO_2-Zr diagram (Fig. GS-9-4), the samples clearly represent a range in compositions. Rhyolitic rocks have low TiO_2 and higher Zr contents and tend to have high Zr/TiO_2 ratios. Basalt and mafic intrusions plot closer to the abscissa on this diagram, i.e., along or immediately above the trend line shown on Figure GS-9-4. Felsic rocks near the bottom of the two drillholes are derived from similar source rocks and plot together, as outlined with the rectangular box, whereas the volcanic sandstones plot towards the field for basaltic rocks. This suggests that the detrital components of the volcanic sandstones represent both felsic and mafic volcanic source rocks. The sample plotting in the top left-hand corner of the diagram is unusual as it contains 62% SiO_2, 19% Al_2O_3 and 5% Fe_2O_3. Although the source is uncertain, the high alumina content suggests abundant clay in the original sediment.

On the feldspar model diagram (Fig. GS-9-5), the samples show a wide range in composition. In general, unaltered basaltic to rhyolitic rocks plot close to, or between, the feldspar model line and the Cpx+plag line and have Al/Zr ratios less than 0.6. The high Al/Zr ratios for most of the rocks in this sample group indicates that they represent clastic and chemical sedimentary material with high Al or unusually low Zr contents. In addition, rocks with a chemical sediment (exhalite) component commonly have Al/Zr ratios greater than 0.6; in hand sample these resemble clastic and volcaniclastic rocks and are probably mixtures of volcanic sediment and exhalite material.

The potassium alteration diagram (Fig. GS-9-6) shows that some of these rocks are altered with Ca and Na depletions and K addition because unaltered volcanic rocks plot to the right of the feldspar model line. These are not intensely altered rocks with respect to Ca and Na because the altered samples plot well within the sericite field on Figure GS-9-5 and therefore have undergone significant K addition.

The REE profiles for the felsic rocks with greater than 70% SiO_2 and the overall composition of rhyolite are

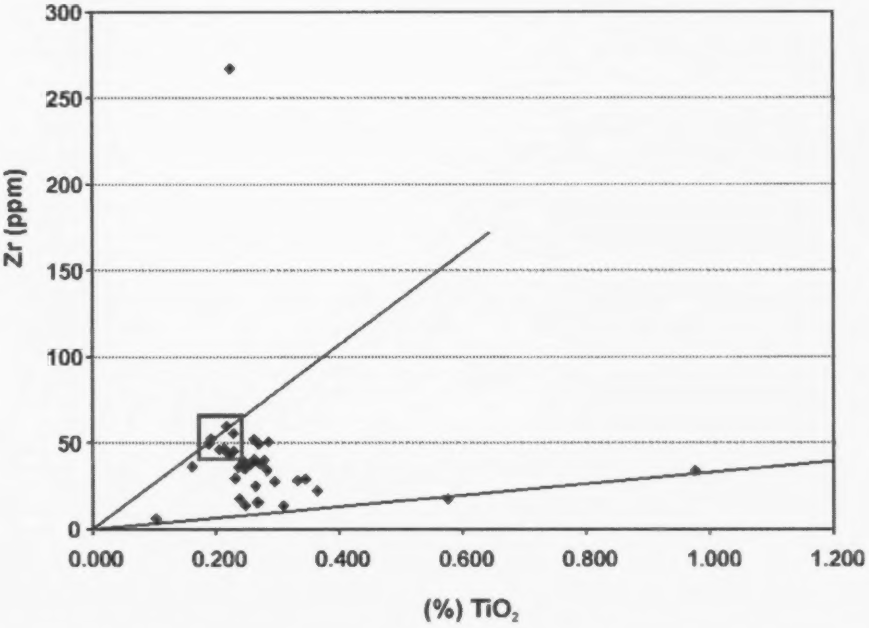


Figure GS-9-4: TiO_2-Zr plot for all samples from drillholes R96-04 and CR-4. Box outlines samples of rhyolite from the lower (relatively unaltered) portion of both drillholes.

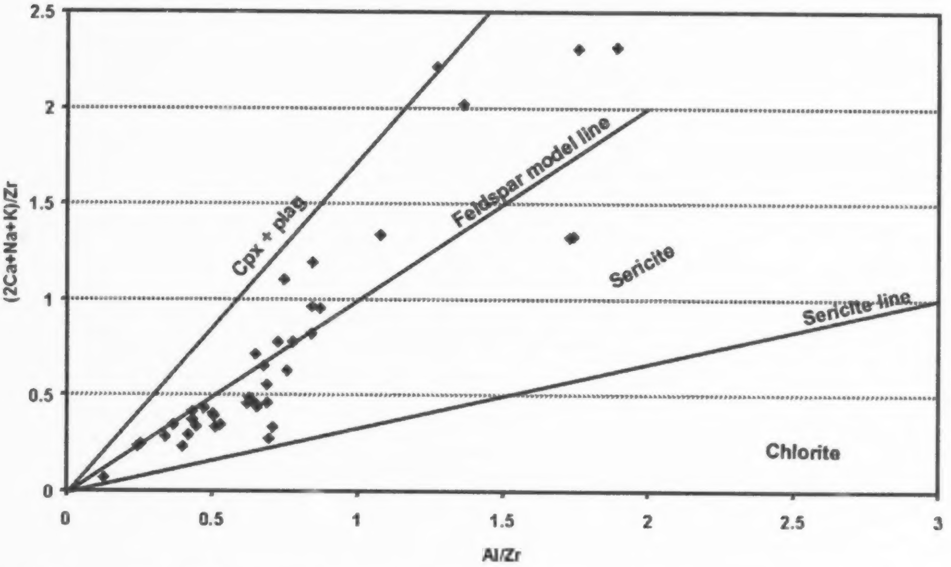


Figure GS-9-5: Feldspar model diagram for all samples (after Madeisky and Stanley, 1993).

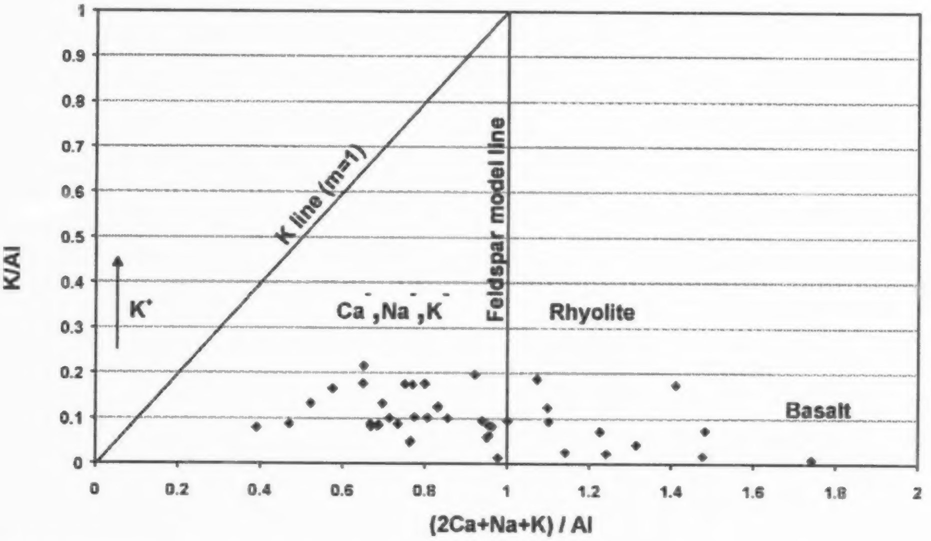


Figure GS-9-6: Potassium alteration diagram for all samples (after Madeisky and Stanley, 1993).

presented in Figure GS-9-7. The rhyolite south of the conductor, sample R96-04-32.3, is distinctly different and has more evolved light REE than those intersected in the lower portions of the drillcores. These rhyolites are considered to represent different source rocks on the basis of their divergent heavy REE profiles. These profiles provide baseline patterns for interpretation of 'mineralized zones' and chemical sedimentary component of volcanosedimentary rocks.

The REE profiles for both grab samples and pulps from two zones of mineralized rocks that represents the conductor in drillhole R96-04 are presented in Figure GS-9-8. There is no correlation between intensity of sulphide mineralization, anomalous Zn, Cu and Ag in individual samples and $Eu^d > 0$. However, rocks with $Eu^d > 0$ occur adjacent to beds with anomalous sulphides and base metal contents. $Eu^d > 0$ values are associated with most VMS type deposits and hydrothermal fluids that can transport and deposit Eu are capable of producing VMS type deposits (cf. Gale et al., 1997).

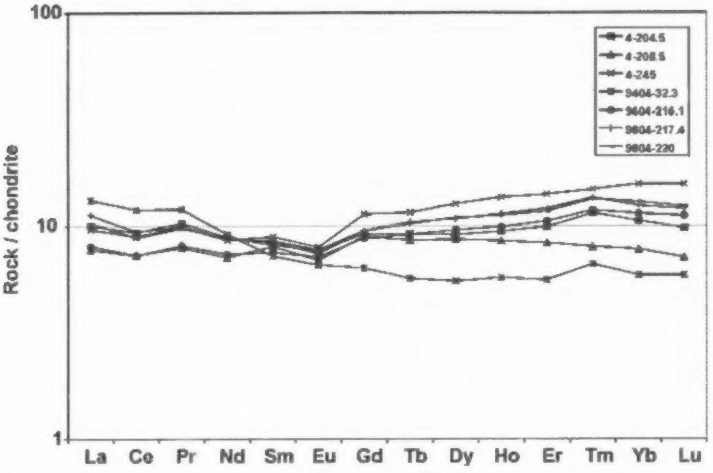


Figure GS-9-7: REE profiles for relatively unaltered 'rhyolite' from drillholes CR-4 and R96-04. Sample number includes start of sample in metres.

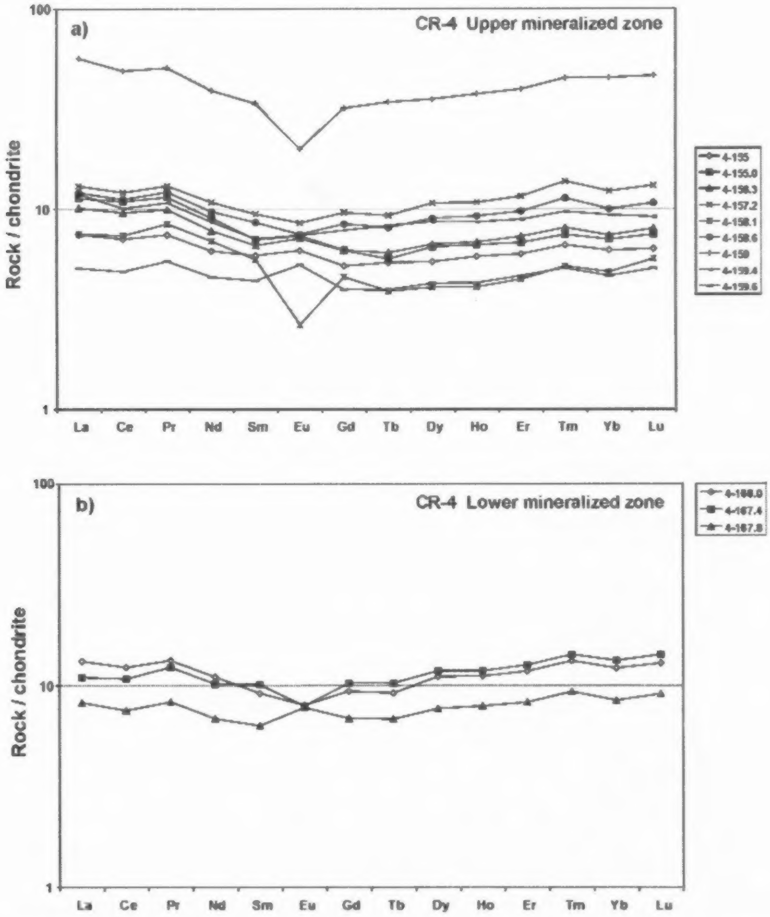


Figure GS-9-8: a) REE profiles for samples from the 'upper' zone of sulphide mineralized rocks in drillhole CR-4; b) REE profiles for samples from sulphide mineralized rocks 6 m below the 'upper' zone.

MUSKEG SAMPLE COLLECTION

Samples of muskeg and underlying Quaternary material were collected using hollow clear plastic tubing fitted with a metal shoe, after the uppermost, frozen portions of the bog were sampled with an ice auger. The plastic tubing was driven into the Quaternary material as far as possible and retrieved with the aid of a winch (Fig. GS-9-2). Compaction of peat occurred within the shoe and tubing and prevented inclusion of excessive water at sites with floating bog. Samples of frozen sphagnum, humified peat, bog iron and quaternary material will be analyzed by selective extraction methods to determine the best medium for further study.

ALDER SAMPLE GEOCHEMISTRY

Clumps of alders 1 to 1.2 m in height are scattered relatively evenly over the Reed Lake bog (Fig. GS-9-2). Bundles of samples were collected in the field and new growth clipped in the laboratory from twigs less than 4 mm in diameter to provide an orientation vegetation survey. The twigs were air dried, ashed and analyzed at Actlabs. Anomalous metal values are present at several sites as shown on figures GS-9-9 and GS-9-10. Of particular interest is the presence of anomalous positive Eu profiles in two of the twig samples that occur adjacent to samples with anomalous Ba, Mo, Re or Au contents. The cause of the anomalous Eu^d values in these two samples will be investigated.

CONCLUSIONS

Geochemical data from drillcores into an electromagnetic conductor indicate that the conductor may define rocks with positive Eu^d values. Comparison with samples from known VMS deposits suggests that these rocks probably represent distal exhalites from a hydrothermal vent capable of producing a base metal deposit. A test survey of alder twig samples over the conductor identified several samples with anomalous metal contents and corresponding anomalous Eu^d values. Further studies of different media from this unique test site will be undertaken.

ACKNOWLEDGMENTS

Douglas Berk and Vio Varga are thanked for collecting the samples under especially difficult conditions. Peter Theyer and Alan Bailes kindly reviewed a draft of the manuscript.

REFERENCES

Gale, G.H., Dabek, L.B. and Fedikow, M.A.F. 1997: The application of rare earth element analyses in the exploration for volcanogenic massive sulfide type deposits; Exploration Mining Geology, v. 6, no. 3, p. 233–252.

Madeisky, H.E. and Stanley, C.R. 1993: Lithogeochemical exploration for metasomatic zones associated with volcanic-hosted massive sulphide deposits using Pearce element ratio analysis; International Geology Review, v. 35, no. 12, p. 1121–1148.

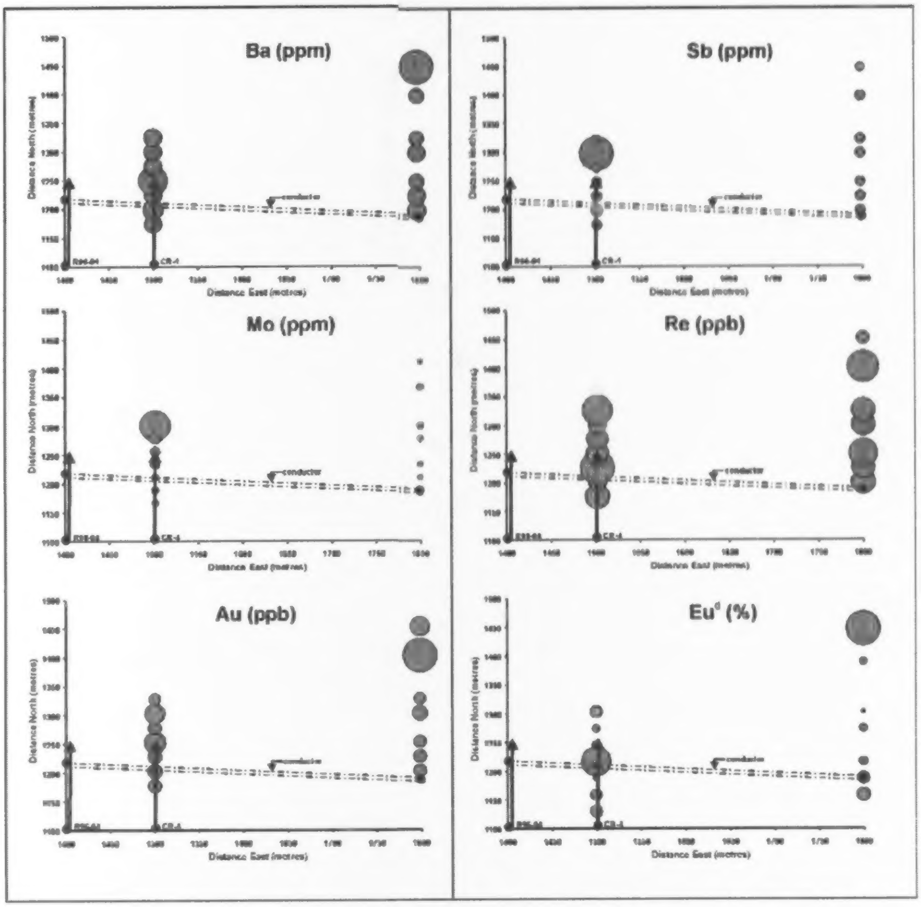


Figure GS-9-9: Metal contents of ashed alders from the Reed property. Range in contents are: Ba - 230 to 920 ppm, Sb - 0.52 to 8.89 ppm, Mo - 1.1 to 29.4 ppm, Re - 2.5 to 8.9 ppb, Au - 33 to 301 ppb, Eu^d - 3 to 321%. The large dots represent maximum values and other values are scaled proportionately.

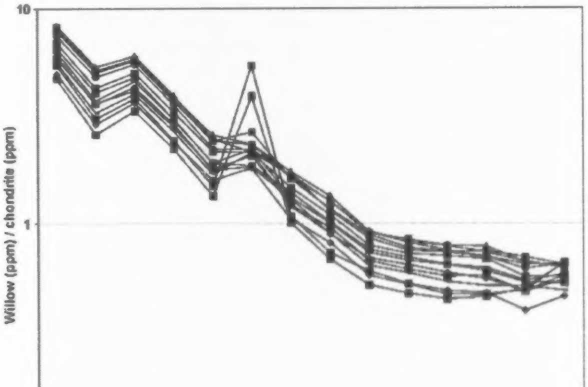
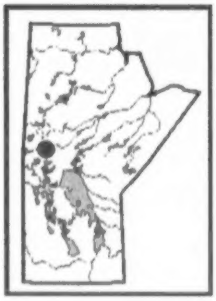


Figure GS-9-10: REE profiles for ashed alders from the Reed property. Note that two of the samples with the lower heavy and light REE metal contents have the highest Eu contents (cf. Figure GS-9-9).

GS-10

GEOLOGY OF THE NEW BRITANNIA MINE, SNOW LAKE (NTS 63K16), MANITOBA

by G.H. Gale



Gale, G.H. 2002: Geology of the New Britannia mine, Snow Lake (NTS 63K16), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 83-86.

SUMMARY

Investigations of the New Britannia mine at Snow Lake indicate that the gold mineralization predates the formation of quartz veins and deformation events recognized to date. The quartz-carbonate-mica schist (QCMS), the main host to the gold mineralization, contains the early particle and mineral lineation that is prevalent in the felsic and mafic country rocks. Deformation events affecting the ores include premetamorphic shear, postmetamorphic boudinage and several late brittle-ductile events that accompanied introduction of carbonate, mobilization of arsenopyrite and gold into late shear foliations, and dissection of the orebody by the very late 'Howe Sound' Fault.

INTRODUCTION

The New Britannia mine has not been studied in detail, although the deposit was discovered in 1927 and production started in 1949. Early studies, including those of Hogg (1957) and Ebbutt (1944), emphasized the relationship between mineralization and the Howe Sound Fault, a late brittle-ductile zone of deformation that is prevalent throughout all orebodies in the mine (Fig. GS-10-1). More recent structural studies have also emphasized the relationship between the ore deposit and faults in the area (Galley et al., 1986; Fieldhouse, 1999). A mineralogical study of the deposit showed that gold generally occurs proximal to acicular arsenopyrite (Fulton, 1999).

The absence of a relationship between mineralization and quartz veins was noted by Wright (1931, p. 95), who was able to examine the original trenches on the property and described the mineralization as follows: "No definite vein or

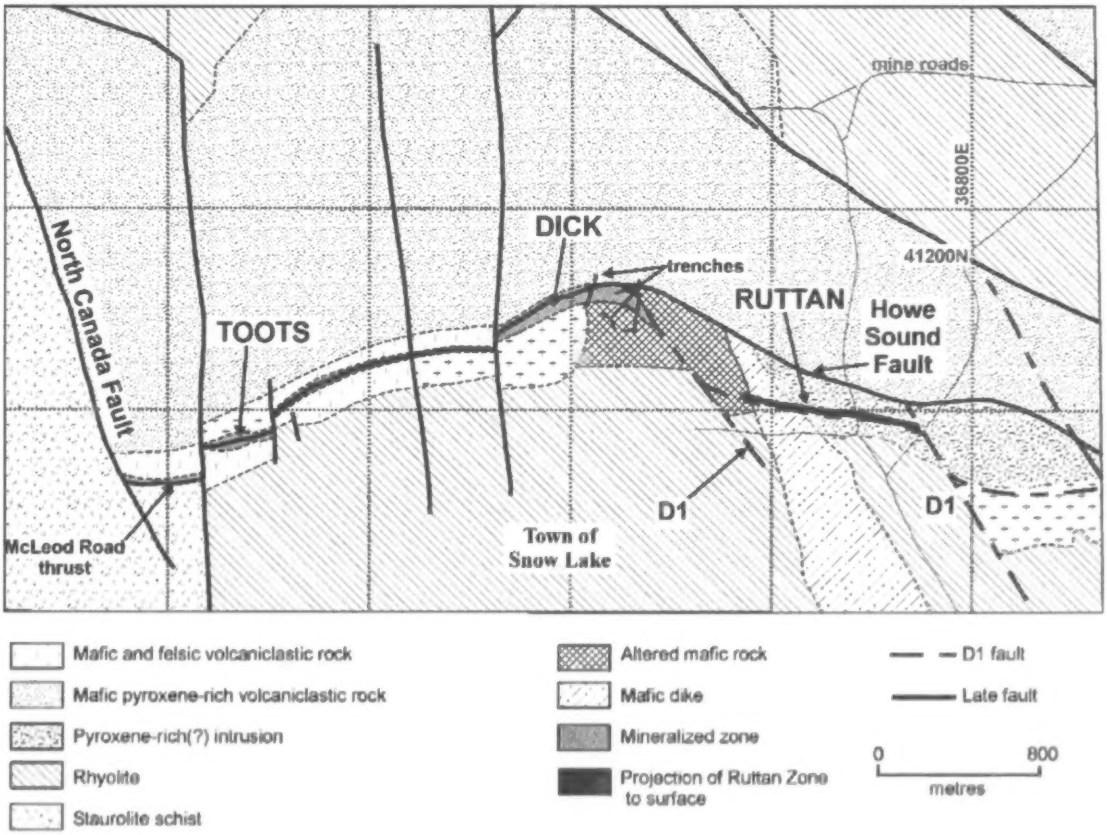

mine roads
36800E
41200N
DICK
trenches
RUTTAN
Howe Sound Fault
TOOTS
North Canada Fault
D1
D1
McLeod Road thrust
Town of Snow Lake
Mafic and felsic volcaniclastic rock
Mafic pyroxene-rich volcaniclastic rock
Pyroxene-rich(?) intrusion
Rhyolite
Staurolite schist
Altered mafic rock
Mafic dike
Mineralized zone
Projection of Ruttan Zone to surface
D1 fault
Late fault
0
800
metres

Figure GS-10-1: Location and general geology of the New Britannia mine.

single large body of quartz has been uncovered in the workings on the property. The quartz on this property is markedly different in appearance from the characteristic gold-bearing quartz of the district." Similar observations were made by Ebbutt (1944), but appear to have been overlooked by later workers.

Detailed mapping of the surface exposures at the New Britannia mine and mineral occurrences in the area indicated to the author that gold occurrences in this area predated deformation of the hostrocks. Studies of the New Britannia underground workings were undertaken on an 'as available' basis, because the mining method provides only a short time interval for geological observations to be undertaken. This ongoing project has provided new insights into the early nature of the deposit and indicates an early pre–Howe Sound and premetamorphism age for the mineralized rocks. This insight may assist further exploration both at the mine and in the area.

GEOLOGICAL SETTING

The orebodies of this deposit are associated mainly with volcaniclastic rocks that include basalt-rhyolite and basalt debris flows with variable amounts of euhedral pyroxene phenoclasts altered to amphibole. These rocks stratigraphically overlie a thick sequence of rhyolite flows and volcaniclastic rocks, and are themselves overlain by a thick sequence of volcaniclastic basalt, pyroxene-phyric basalt and related tuff. Pyroxene-bearing mafic dikes and sills, which appear to be feeders to the overlying pyroxene-bearing rocks, cut both the rhyolite and the enclosing volcaniclastic rocks, but none have been identified to date within the orebodies. The immediate country rock to the orebodies varies throughout the mine and includes layered volcaniclastic rocks, massive pyroxene-bearing basalt flows or intrusions, altered basalt and rhyolite.

MINERALIZATION

The main ore type in the mine is 'quartz-carbonate-mica schist' (QCMS) that varies from fine-grained sucrose and massive where mica contents are low, to weakly to moderately foliated where lineated reddish brown mica (phlogopite) is abundant. Several ages of quartz veins are present throughout the mine and are especially thick at the edges of, and between, boudinaged lenses of QCMS. Quartz veins are barren unless they contain angular fragments of QCMS, and gold grades within them correlate directly with the quantity of QCMS present. Arsenopyrite in the QCMS occurs mainly as acicular crystals, typically 0.5 mm in diameter and 2 to 3 mm in length, with a preferred orientation that parallels particle and mineral lineation in the surrounding host rocks.

Locally, mineralized mafic schist, developed from sheared mafic country rocks, contains up to 5% arsenopyrite and significant gold. This mineralization is quite different from the QCMS, in that the mafic rock has a strong foliation and the arsenopyrite crystals are equant, 1 mm in size and commonly concentrated along foliation planes in the mafic schist. This mineralization postdates the fabric in the mafic schist, and the formation of the mafic schist postdates the mineral lineation in the QCMS.

Although carbonate alteration has long been considered an original feature of the QCMS ore, it is apparent that the honey-coloured carbonate veins postdate the development of early quartz veins but predate development of the Howe Sound Fault, because both carbonate veins and faults cut the QCMS and the Howe Sound Fault also clearly cuts carbonate veins. The carbonate also replaces lineated mafic rocks (Fig. GS-10-2) and produces a nonlineated, massive, beige-coloured rock, in some parts of the mine, that is barren of gold but cut by late veinlets of pyrite; pyrite occurs as a coating on one set of faults related to the Howe Sound Fault. Some of the deformational events affecting the QCMS and ore are illustrated in Figure GS-10-3.

The relative age of mineralization in the New Britannia mine is consistent with the age of mineral deposits and occurrences examined on surface (Gale, 1997). Specifically, the arsenopyrite and gold predate the dominant particle and mineral lineation (L>>S) observed in the country rocks and definitely predate the formation of tensional quartz veins.

EXPLORATION CONSIDERATIONS

Although the origin of the deposit is uncertain, it can be demonstrated that the Howe Sound Fault follows the mineralization and is not, as previously envisaged, the locus for mineralizing fluids. In addition, deformation at the ends of orebodies illustrates that the mineralization was dragged and/or rotated into the plane of the North Canada Fault and related structures, and therefore predates the latest, if not all, movements on that structure.

The author contends that the New Britannia, 3 Zone and Birch orebodies are all early mineralized features. These orebodies can be expected to continue along strike, independent of the position of late brittle features, such as the Howe

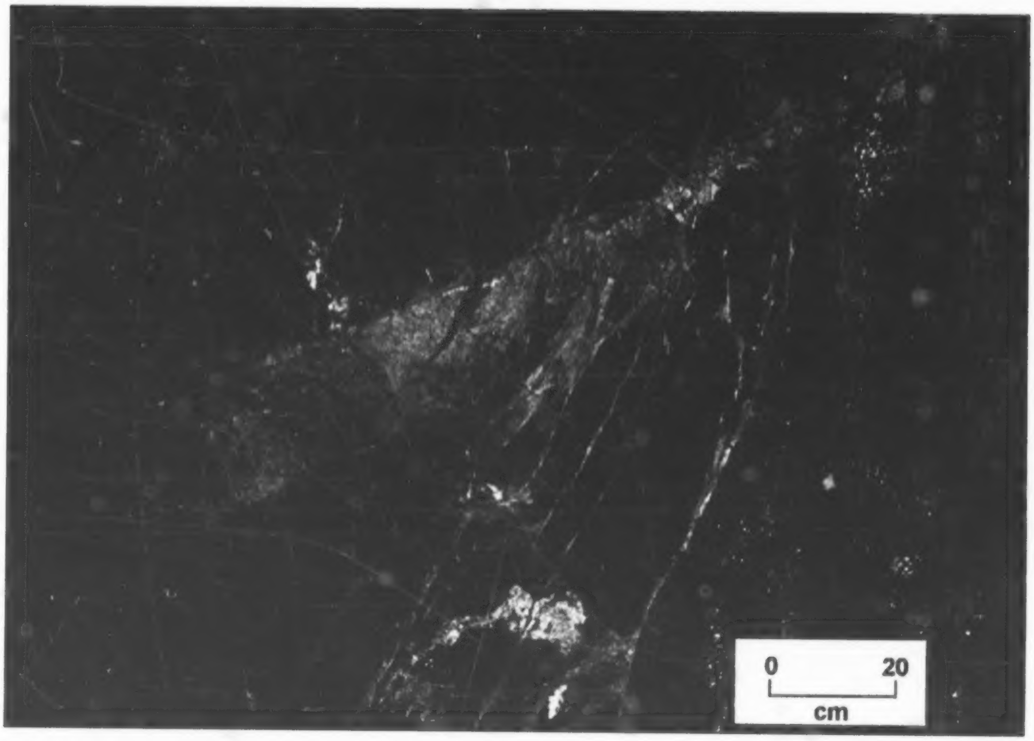


Figure GS-10-2: Iron-magnesium carbonate replacement accompanying Riedel shear in mafic volcaniclastic rocks adjacent to ore, New Britannia mine.

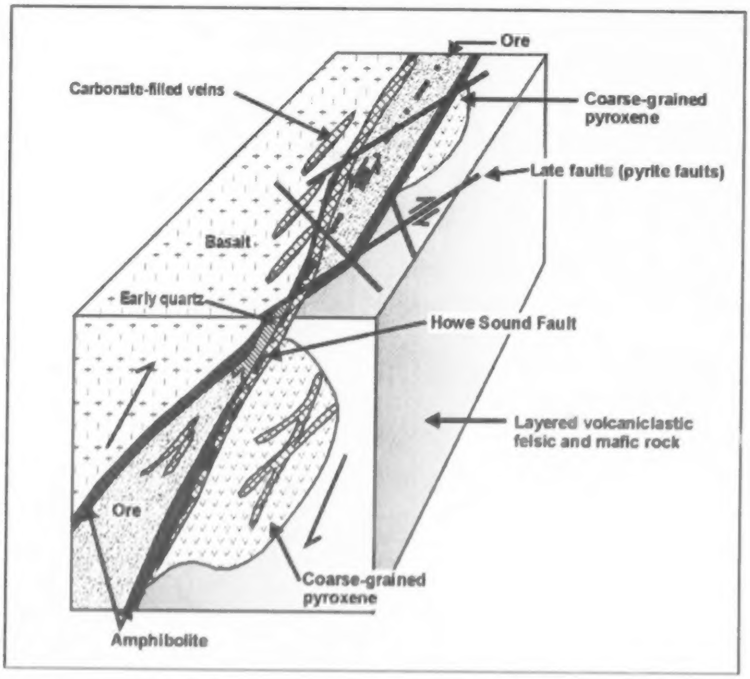

Ore
Carbonate-filled veins
Coarse-grained pyroxene
Late faults (pyrite faults)
Basalt
Early quartz
Howe Sound Fault
Layered volcaniclastic felsic and mafic rock
Ore
Coarse-grained pyroxene
Amphibolite

Figure GS-10-3: Schematic block diagram illustrating deformation of quartz-carbonate-mica schist and ore. 'Amphibolite' represents lineated hornblende in recrystallized mylonitized mafic rocks along the margin of the orebodies.

Sound Fault. Location of the extensions of these deposits will require careful mapping and reconstruction of the local geology.

ACKNOWLEDGMENTS

This study is being carried out in conjunction with the geological staff at the New Britannia mine, and their continued assistance and contributions to the project are greatly appreciated. Peter Theyer kindly reviewed an early draft of the manuscript.

REFERENCES

Ebbutt, F. 1944: The Nor-Acme property of the Howe Sound Exploration Company Ltd; Precambrian, v. 17, no. 7, p. 7–12.

Fieldhouse, I. 1999: Geological setting of gold mineralization in the vicinity of the New Britannia Mine, Snow Lake, Manitoba; M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 136 p.

Fulton, P.J. 1999: Distribution of gold mineralization at the New Britannia Mine in Snow Lake, Manitoba; M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 209 p.

Gale, G.H. 1997: Geological settings and genesis of gold mineralization in the Snow Lake area (NTS 63K/16); *in* Report of Activities 1997, Manitoba Energy and Mines, Geological Services, p. 73–78.

Galley, A.G., Ziehlke, D.V., Franklin, J.M., Ames, D.E. and Gordon, T.M. 1986: Gold mineralization in the Snow Lake–Wekusko Lake region, Manitoba; *in* Gold in the Western Shield, L.A. Clark (ed.), Canadian Institute of Mining and Metallurgy, Special Volume 38, p. 379–98.

Hogg, N. 1957: Nor-Acme mine; *in* Structural Geology of Canadian Ore Deposits, Canadian Institute of Mining and Metallurgy, Congress Volume, p. 262–275.

Wright, J.F. 1931: Geology and mineral deposits of a part of northwest Manitoba; Geological Survey of Canada, Summary Report, 1930, Part C, p. 93C–95C.

GS-11 PLATINUM GROUP ELEMENT INVESTIGATIONS IN THE FLIN FLON GREENSTONE BELT: REGIONAL GEOLOGY OF THE MCBRATNEY LAKE PGE-AU OCCURRENCE AND PART OF THE MIKANAGAN LAKE SILL (NTS 63K13), MANITOBA

by P. Theyer and T. Heine

Theyer P. and Heine T. 2002: Platinum group element investigations in the Flin Flon greenstone belt: regional geology of the McBratney Lake PGE-Au occurrence and part of the Mikanagan Lake Sill (NTS 63K13), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 87-93.

SUMMARY

Geological investigations in the Flin Flon greenstone belt oriented toward platinum group elements (PGE) focused on four related topics:

1) A detailed investigation of the petrography and mineralogy of the McBratney Lake PGE-Au occurrence was carried out to elucidate the possible origin and formation of this mineralization. Preliminary results, indicating that the mineralization is probably hydrothermal in origin, are presented elsewhere (Olivo et al., GS-12, this volume).

2) An investigation of the lithology, composition and age of the Wonderland Lake gabbro was undertaken because it hosts two PGE-bearing sulphide occurrences along its intrusive contact with the Bear Lake basaltic andesite (Theyer, 2001). Preliminary results indicate that the igneous body is a heterolithic magmatic complex. The intrusion is important, as it belongs to a group of pre-Missi, differentiated, mafic to intermediate intrusions (Bailes and Syme, 1989), several of which are spatially associated with PGE mineralization in the Bear Lake Block.

3) Geological mapping and sampling of the area adjacent to the McBratney mineral occurrence was undertaken in an attempt to determine the source of the PGE mineralization and to elucidate the particular geological and/or tectonic parameters leading to its formation. Preliminary results indicate that the McBratney mineralization is underlain by mafic, intermediate and felsic volcanic rocks associated with sulphide-bearing horizons, and that gabbro makes up a minor part of the surrounding rock sequence.

4) A geological investigation designed to evaluate the PGE potential of other gabbroic bodies in the belt was initiated with the Mikanagan Lake Sill. Shear-hosted sulphide mineralization from the gabbro zone of the sill returned anomalous Pd+Pt concentrations.

INTRODUCTION

The McBratney Lake PGE-Au occurrence, located approximately 7 km east of Flin Flon, is of significance to mineral explorationists due to its exceptionally high PGE and Au concentrations. The occurrence is also significant because the 'Bear Lake Block' of the Flin Flon greenstone belt, previously known to host two VMS deposits (Cuprus and White Lake mines) and a number of VMS mineral occurrences (Bailes and Syme, 1989), is now also known as a potential host to significant PGE mineralization. The McBratney Lake PGE-Au mineralization, exposed in a pit excavated in 2001, straddles the contact of (?)pre-Missi gabbro and Bear Lake basaltic andesite (Theyer, 2001).

REGIONAL SETTING

The Flin Flon greenstone belt, which belongs to the juvenile (internal) zone of the Trans-Hudson Orogen (Hoffman, 1988), is a collage of 1.92 to 1.88 Ga tectonostratigraphic assemblages juxtaposed during 1.88 to 1.87 Ga intra-oceanic accretion and subsequent 1.84 to 1.78 Ga terminal collision of the bounding Archean cratons (Lucas et al., 1996). Based on their trace-element contents, volcanic rocks in the Flin Flon greenstone belt are known to include juvenile-arc (approx. 68%), juvenile ocean-floor (approx. 20%), and minor (approx. 12%) oceanic-plateau, ocean-island basalt, 'evolved' plutonic-arc and undivided rocks (Syme and Bailes, 1993; Stern et al., 1995a, b; Syme et al., 1999). Oceanic-arc assemblages include tholeiite, calc-alkaline and rare shoshonite and boninite suites (Stern et al., 1995a) that are almost identical to those forming in modern intra-oceanic arcs (e.g., Gill, 1981). These volcanic assemblages are unconformably overlain by a terrestrial metasedimentary sequence (Missi Group) and are intruded by a complex array of intrusive rocks (Bailes and Syme, 1989). Most of the intrusive rocks in the central Flin Flon greenstone belt predate the Missi Group. In the Flin Flon–White Lake area, Bailes and Syme (1989) defined major fault-bounded blocks, each comprising unique stratigraphic successions (Fig. GS-11-1).

The Bear Lake Block, one of the fault-bounded blocks, is a 5 km thick, east-facing sequence of lava flows and volcaniclastic rocks bounded on the west by the Inlet Arm Fault and on the east by the Northeast Arm Fault (Bailes and Syme, 1989). This block has been subdivided into eleven lithological units, ranging from andesitic basalt to rhyolite and including associated detrital metasedimentary rocks and massive-sulphide deposits. Dominating most of the

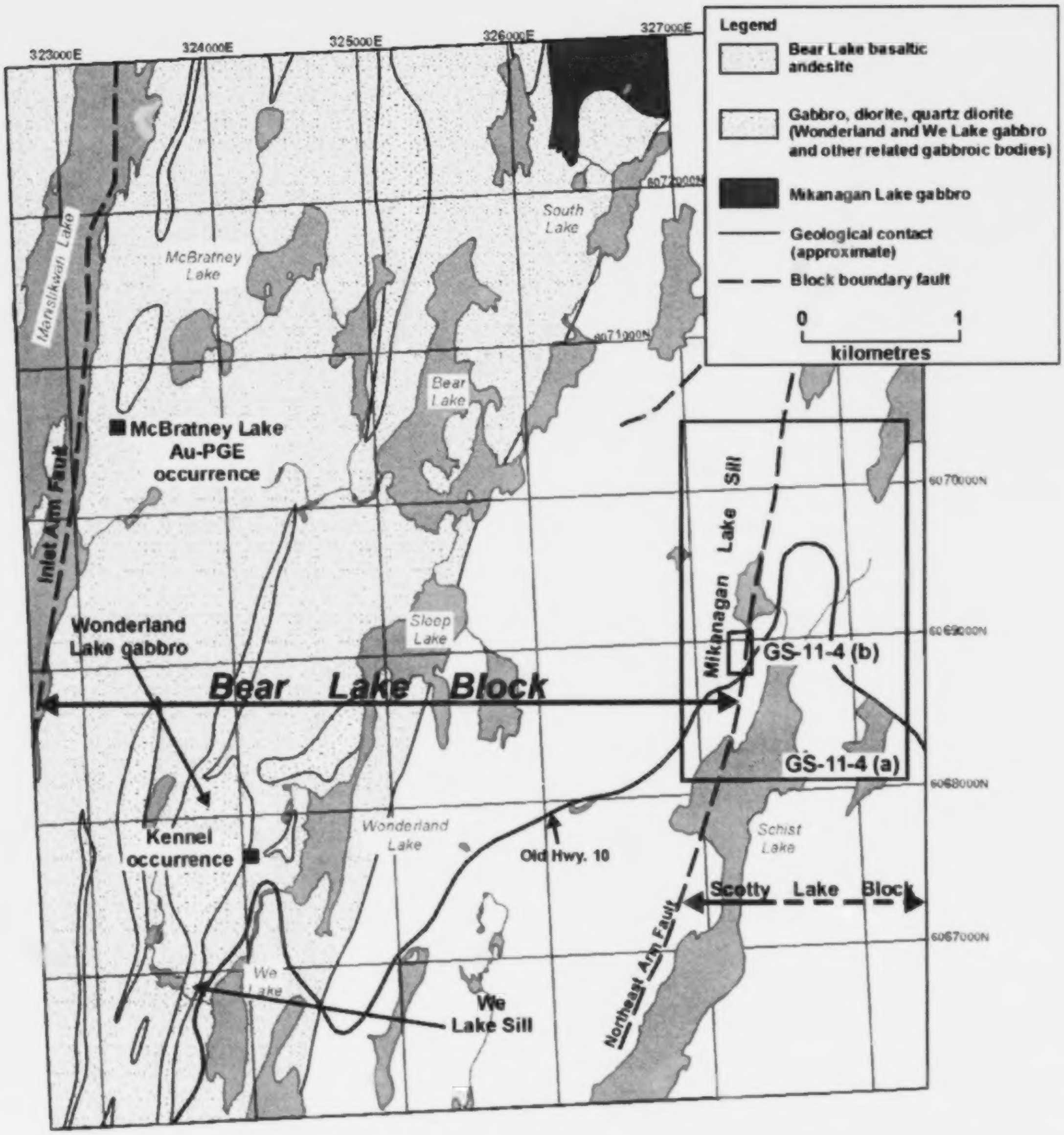

323000E
324000E
325000E
326000E
327000E
6072000N
6071000N
6070000N
6069000N
6068000N
6067000N
Legend
Bear Lake basaltic andesite
Gabbro, diorite, quartz diorite (Wonderland and We Lake gabbro and other related gabbroic bodies)
Mikanagan Lake gabbro
Geological contact (approximate)
Block boundary fault
0
1
kilometres
Manistikwan Lake
McBratney Lake
South Lake
Bear Lake
McBratney Lake Au-PGE occurrence
Inlet Arm Fault
Mikanagan Lake Sill
GS-11-4 (b)
GS-11-4 (a)
Sleep Lake
Wonderland Lake gabbro
Bear Lake Block
Kennel occurrence
Wonderland Lake
Old Hwy. 10
Schist Lake
Scotty Lake Block
Northeast Arm Fault
We Lake
We Lake Sill

Figure GS-11-1: Flin Flon–White Lake area, showing the location of the Bear and Scotty Lake blocks, bounding faults and study areas (modified after Bailes and Syme, 1989).

western part of the Bear Lake Block and forming its base is the Bear Lake basaltic andesite, comprising a number of volcanic flows that together exceed 3.3 km thickness. Intermediate to felsic volcaniclastic units overlie the basaltic andesite sequence.

GEOLOGY IN THE VICINITY OF THE MCBRATNEY LAKE PGE-AU OCCURRENCE

This section deals with the geological setting of the McBratney Lake PGE-Au mineralization, as determined through examination of abundant and clean outcrops, especially in the northern and eastern parts of the now-flooded pit that exposed the mineralization (Fig. GS-11-2). The petrography and mineralogy of this occurrence is the subject of a separate study initiated in collaboration with Queens University (Olivo et al., GS-12, this volume). That study highlights the significance of hydrothermal mineralization and/or remobilization and PGE redistribution in the origin of the McBratney Lake PGE-Au mineralization. A description of the geological units in the vicinity of the occurrence is given below. The unit numbers correspond to those on Figure GS-11-2.

Bear Lake basaltic andesite (unit 1)

Well-preserved pillowed flows of the Bear Lake basaltic andesite suite are exposed east of Manistikwan (Big Island) Lake. Pillows range in length from 1 to 3 m, with selvages ranging from 5 to more than 30 mm in thickness. Interpillow material, consisting mainly of selvage fragments and hyaloclastite, can attain a thickness of more than 10 cm.

Traverses from Manistikwan Lake to the area of the McBratney Lake PGE-Au occurrence showed a distinct increase in the amount of both epidotization and deformation in an easterly direction. Adjacent to the shore of Manistikwan Lake, pillows showing little deformation are characterized by negligible epidotization that affects mainly their central zones. However, gradual but dramatic increases in both the degree of deformation (flattening and stretching) of the pillows and the intensity of epidotization was observed approximately 150 m east of Manistikwan Lake. At this location, pillows measuring 0.5 to 1 m in width attain lengths of several metres and contain massive, oval to subrounded, decimetre-size epidosite (epidote+quartz) domains. An even greater intensity of deformation and

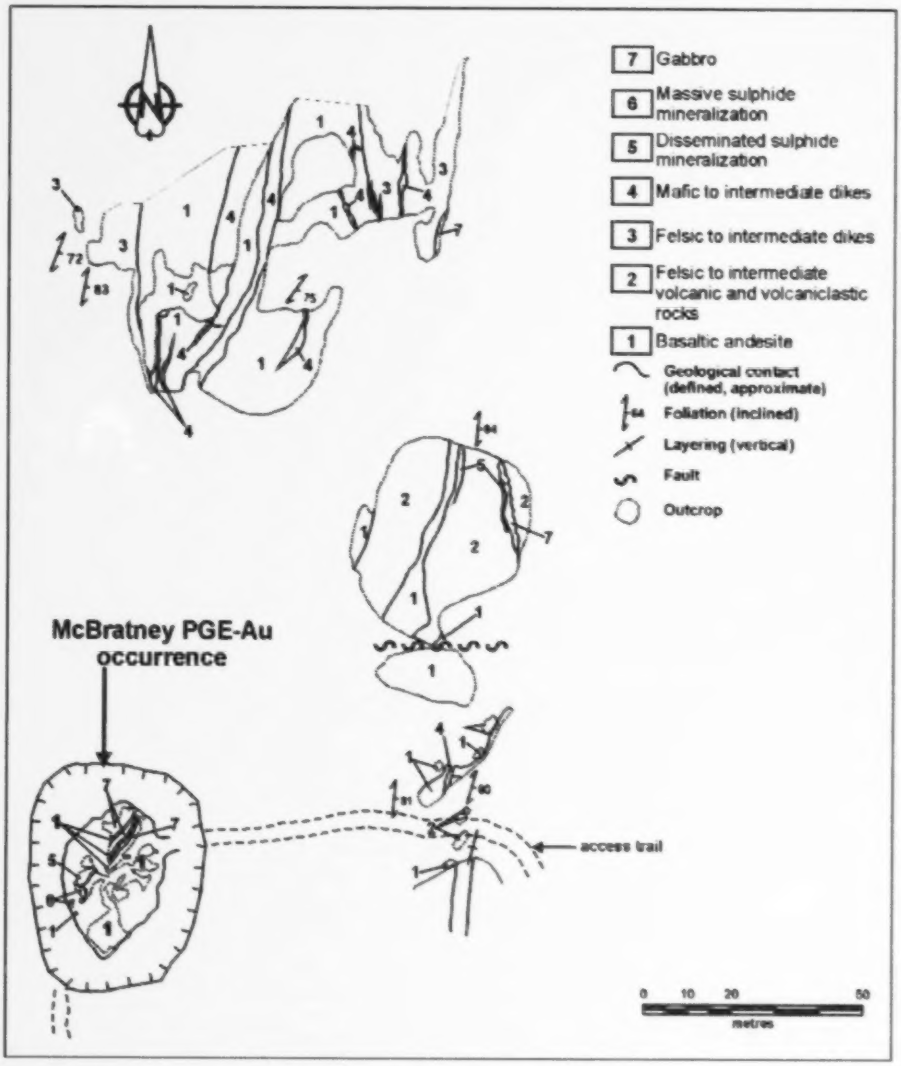

7 Gabbro
6 Massive sulphide mineralization
5 Disseminated sulphide mineralization
4 Mafic to intermediate dikes
3 Felsic to intermediate dikes
2 Felsic to intermediate volcanic and volcaniclastic rocks
1 Basaltic andesite
Geological contact (defined, approximate)
Foliation (inclined)
Layering (vertical)
Fault
Outcrop
McBratney PGE-Au occurrence
access trail
0
10
20
50
metres

Figure GS-11-2: Geological map of the vicinity of the McBratney Lake PGE-Au occurrence.

epidote alteration was observed in outcrops directly north of the McBratney Lake PGE-Au occurrence. In these exposures, the pillowed basalt consists of a contorted mass of lensoid epidosite and quartz domains (Fig. GS-11-3).

Bailes and Syme (1989) observed a positive correlation between the intensities of deformation and epidotization. Galley and Bailes (2001) are investigating the correlation of epidotization and high-temperature hydrothermal subseafloor alteration, which may be associated with the mobilization of large quantities of metals.

Felsic to intermediate volcanic and volcaniclastic rocks (unit 2)

Extensive outcrops of felsic to intermediate volcanic rocks, which weather beige to grey-green, occur northeast of the McBratney Lake PGE-Au exploration pit. This unit is composed of several subunits, each up to a metre thick, that can be distinguished based on subtle compositional and colour variations. Many of the rocks are porphyritic, composed of a fine-grained quartz and plagioclase groundmass hosting approximately 5% millimetre-size, euhedral plagioclase and minor, equally large, strained, mosaic quartz crystals. A north-striking layer, approximately 2 cm thick and characterized by well-rounded carbonate grains ranging from 1 to 2 mm in diameter, is tentatively interpreted as a tuff.

Several outcrops of a greenish grey siliceous rock underlie the eastern access trail to the McBratney pit. These are interpreted as rhyolite.

Felsic to intermediate dikes (unit 3)

Coarse-grained, chloritized and epidotized rock, in places containing abundant pyrite cubes, up to a centimetre in size, constitute some of the outcrops north of the pit. Thin sections show that the rock is composed mainly of coarse epidote, minor quartz, plagioclase and chlorite.

Mafic to intermediate dikes (unit 4)

These are foliated, fine-grained rocks characterized by smooth-weathering, grey surfaces. These rocks occur as concordant units, ranging from a centimetre to a metre in thickness and up to 20 m long, with sharp, well-defined, abrupt contacts. They are uniformly fine grained, both along and across strike, and there is no evidence of chilled margins. The rock is composed of approximately 50% epidote, 20% chlorite, 20% amphibole, 10% quartz and accessory opaque minerals. They are tentatively interpreted as selectively epidotized dikes; however, they may also be of sedimentary origin, as they are subparallel to stratigraphy.

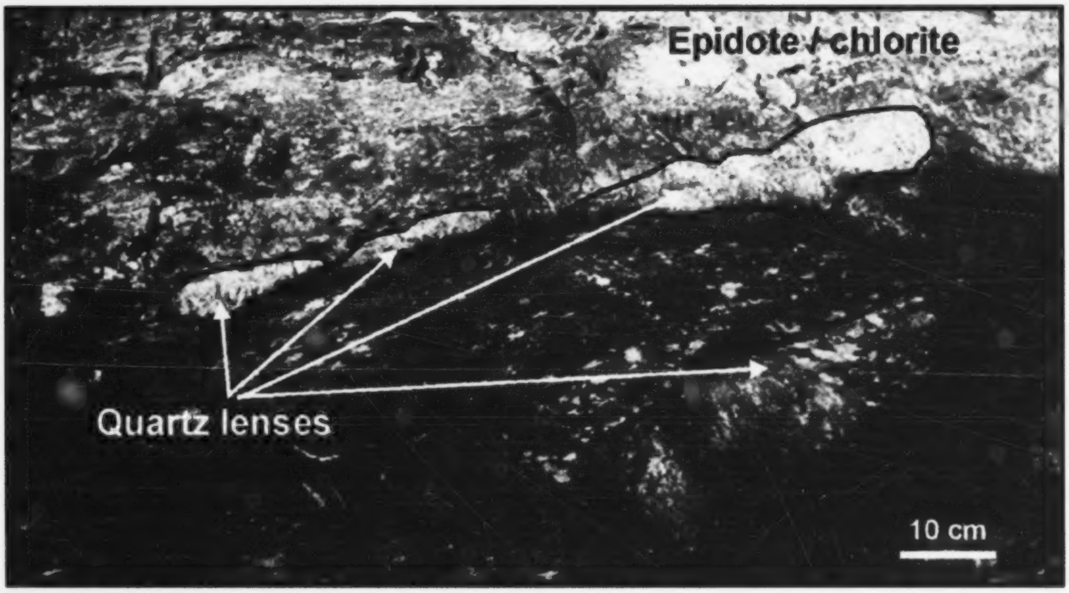


Figure GS-11-3: Deformed and contorted epidosite, quartz and schist. The rock is a pillowed basalt in a zone of intense deformation in the immediate vicinity of the McBratney Lake PGE-Au occurrence.

Disseminated sulphide mineralization (unit 5)

Disseminated sulphide mineralization, hosted by bleached, altered rocks, consistently occurs with felsic rock units. The sulphide minerals occur as disseminated to centimetre-thick layers of pyrrhotite and minor pyrite. Most of the sulphide layers are deeply weathered, with bright red to yellow limonitic crusts. The persistent and repeated association of sulphide units and felsic volcanic rocks has been identified in a preliminary way over a distance of several hundreds of metres north and east of the McBratney pit.

Massive sulphide mineralization (unit 6)

Massive sulphide mineralization occurs in a lens that was exposed in the McBratney test pit in 2001 (Theyer, 2001). The sulphide mineralization underlying the pit comprises an assemblage of pentlandite, Ni-bearing pyrrhotite, pyrite, bravoite, marcasite, chalcopyrite, millerite, sphalerite and galena (Olivo et al., GS-12, this volume).

Gabbro (unit 7)

Gabbro occurs as thin (a decimetre to several metres thick), deformed, elongated, north-striking lenses. Contacts with adjoining rocks are sheared and disrupted. In places, the margins of the gabbro are characterized by quartz-filled tension gashes. Thin sections show a coarse-grained, altered magmatic unit composed of plagioclase, amphibole and felted sericite and chlorite masses. Quartz occurs as secondary vein fillings.

MIKANAGAN LAKE SILL

The Mikanagan Lake Sill is one of several large, differentiated, tholeiitic gabbroic intrusions that occur in the Flin Flon greenstone belt. Described by Bailes and Syme (1989), the sill is approximately 15 km long and 1.2 km thick, well differentiated and indicates stratigraphic tops to the east. This intrusion is one of several in the Flin Flon belt that will be investigated for their potential to host PGE mineralization.

Platinum group element–bearing sulphide zone

Fracture-controlled PGE-bearing sulphide mineralization occurs within the gabbro zone near the southern end of the Mikanagan Lake Sill, in an area measuring approximately 120 by 30 m (Fig GS-11-4). The mineralized zones in

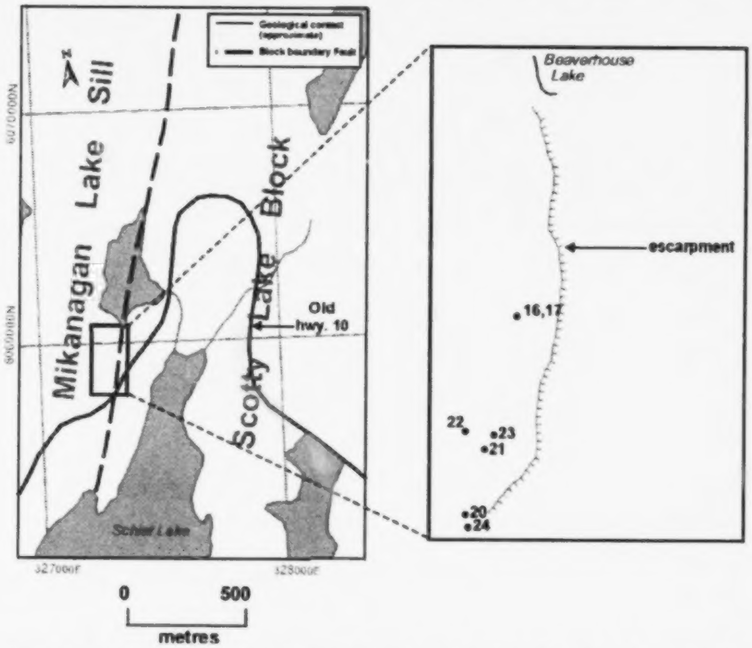


Figure GS-11-4: Geological sketch map showing the location of PGE-bearing sulphide mineralization in the Mikanagan Lake Sill (geology modified after Bailes and Syme, 1989).

this area appear to have a limited distribution, each generally encompassing several square metres. Some of these areas are intensely foliated. The weathered rock surface is grey to green-grey, and the almost complete absence of iron oxide on the surface of sulphide-bearing gabbro makes the recognition of sulphide-bearing zones a challenging task.

Thin sections of several of the mineralized zones show that the hostrock consists of variably altered gabbro. Bailes and Syme (1989) described the alteration sequence of the various parts of the Mikanagan Lake Sill in detail. Thin-section descriptions will thus be kept brief. Coarse-grained, amphibolitized pyroxene is partially altered to chlorite and tremolite aggregates and overprinted by epidote. Plagioclase is rarely well preserved, and is generally completely sericitized and epidotized. Several sections contain up to 5% strained quartz. Opaque subhedral minerals are rare.

Mineralized rocks are characterized by a variety of alteration types, including chloritization, carbonatization and epidotization. Each of these alteration types may occur by itself or in conjunction with the others. The alteration can completely obliterate the original textures, resulting in a chlorite-carbonate-epidote rock.

Pyrrhotite is the dominant sulphide mineral, generally as fine-grained disseminations, and attains concentrations of up to 10%. Pyrite is a minor constituent, rarely exceeding 1%. Minor chalcopyrite is also present.

Table GS-11-1 includes some of the rock sample locations (UTM co-ordinates given), the sample numbers and the results of selected Pt, Pd and Au analyses. The analyses were performed by XRAL Laboratories, using a fire-assay preconcentration step, with PbO as a collector, and analysis by mass spectrometry (FAMS 30 analytical procedure). Lower detection limits of this method are 1 ppb Au, 1 ppb Pd and 0.5 ppb Pt.

Table GS-11-1: Gold, platinum and palladium concentrations in gabbro samples from the Mikanagan Lake Sill. Detection limits: 1 ppb Au, 1 ppb Pd, 0.5 ppb Pt.

Sample No.	UTM co-ordinates[1]		Au (ppb)	Pd (ppb)	Pt (ppb)
	Easting	Northing			
16	327283	6069147	<1	3	2.5
17	327283	6069147	2	5	6.4
20	327253	6069025	2	40	9.4
21	327264	6069065	51	461	108
22	327264	6069074	7	352	56.5
23	327269	6069073	5	109	49.9
24	327254	6069018	4	152	69.1

Discussion

Of the eight rock samples collected from gabbro of the Mikanagan Lake Sill that were analyzed, four contain anomalous Pt+Pd concentrations (Table GS-11-1; Pt+Pd > 100 ppb is defined as anomalous).

Three samples (samples 21, 22 and 23) cluster in an area measuring approximately 40 m^2 The fourth anomalous sample (sample 24) was collected approximately 50 m south of the aforementioned cluster.

The rock sample with the highest Pt+Pd concentration (sample 21) was collected from a medium-grained, grey-weathering gabbro with minor rusty patches. It is characterized by abundant fractures and shear zones. In an area measuring 2 by 1.5 m, up to 5% pyrrhotite and minor chalcopyrite occur as irregular masses and disseminations. Sample 22 was collected from a small (<1 m^2) outcrop of strongly carbonatized and epidotized, medium-grained gabbro containing patches of up to 5% pyrrhotite and traces of chalcopyrite. Sample 23 is from epidotized and carbonatized gabbro containing up to 10% pyrrhotite masses with minor chalcopyrite.

Sample 24 was collected from a fresh-looking, medium-grained gabbro with a grey to black mottled appearance caused by fresh amphibole intergrowths with plagioclase. The relatively high Pt+Pd concentration in this sample is remarkable, considering that it contains only traces of pyrrhotite.

The occurrence of anomalous Pt+Pd concentrations in gabbro of the Mikanagan Lake Sill indicates that this intrusion has the potential to contain economic quantities of PGEs. Follow-up work on the presently recognized mineralized zones will include detailed studies of their lithology and geochemistry. Additional studies of the igneous complex will include identification of sulphide-bearing areas.

WONDERLAND LAKE GABBRO

The discovery of PGE-bearing sulphide mineralization at the eastern contact of the Wonderland Lake gabbro with the Bear Lake basaltic andesite, and at the contact between the basaltic andesite and another gabbro body at the McBratney mineral occurrence, indicates that the contact between the basalt units and gabbro bodies may be significant for the occurrence of PGE mineralization (Theyer, 2001). Current studies of the McBratney PGE-Au mineral occurrence, based on investigations of drill core and sulphide mineralization samples, show that the occurrence is of hydrothermal origin and that the sulphide minerals intersected by exploratory drilling are hosted by basaltic andesite (Olivo et al., GS-12, this volume).

Several traverses across the Wonderland Lake gabbro were undertaken in 2002 to collect rock samples for geochemical and lithological investigations. A large rock sample intended for age determination was also collected from a pegmatitic phase of the gabbro.

Field evidence indicates that the Wonderland Lake gabbro is a geologically inhomogeneous body comprising a variety of rock types, including granite, diorite and gabbro. A crude lithological zonation, based on a relative increase of felsic rocks in an easterly direction, is recognizable. However, magma mixing that resulted in large, randomly located areas of hybrid granitic to dioritic rocks, characterized by melanocratic inclusions, schlieren and bands contained in a more felsic matrix, is common and weakens the notion of an orderly zonation. Moreover, east-striking, modally layered leuco- and melagabbro indicate further inhomogeneities. Discrete, sharply defined sulphide-bearing zones, up to several metres in size and containing up to 10% coarse-grained, recrystallized pyrite, occur in the central part of the Wonderland Lake gabbro. The composition of these zones and the amount and type of alteration are comparable to those of the gabbroic hostrock. They can, however, be differentiated based on their distinctly finer grain sizes and their ubiquitous sulphide content, which results in red and brown limonitic oxidation on weathered surfaces.

ACKNOWLEDGMENTS

Hudson Bay Mining and Development Co. Ltd. and Fort Knox Gold Resources Inc. are both gratefully acknowledged for their permission to access records and view and sample drill core, and for their time spent in geological discussions.

S. Masson (M'Ore Resources) is acknowledged for introducing and guiding the authors to his PGE property on the Mikanagan Lake Sill.

The author also wants to thank his colleague, G.R.Olivo, for her patient fortitude while introducing him into the complexities of magmatic versus hydrothermal mineralizing environments.

REFERENCES

Bailes, A.H. and Syme, E.C. 1989: Geology of the Flin Flon–White Lake area; Manitoba Energy and Mines, Minerals Division, Geological Report 87-1, 313 p. and 2 maps at 1:20 000 scale.

Galley, A.G. and Bailes, A.H. 2001: Flin Flon Targeted Geoscience Initiative; *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 9–17.

Gill, J.B. 1981: Orogenic Andesite and Plate Tectonics; Springer Verlag, New York, 390 p.

Hoffman, P.F. 1988: United plates of America, the birth of a craton: Early Proterozoic assmbly and growth of Laurentia; Annual Review of Earth and Planetary Sciences, v. 16, p. 543–603.

Lucas, S.B., Stern, R.A., Syme, E.C., Reilly, B.A. and Thomas, D.J. 1996: Intraoceanic tectonics and the development of continental crust: 1.92–1.84 Ga evolution of the Flin Flon Belt, Canada; Geological Society of America Bulletin, v. 108, no. 5, p. 602–629.

Stern, R.A., Syme, E.C., Bailes, A.H. and Lucas, S.B. 1995a: Paleoproterozoic (1.90–1.86 Ga) arc volcanism in the Flin Flon Belt, Trans-Hudson Orogen, Canada; Contributions to Mineralogy and Petrology, v. 119, no. 2–3, p. 117–141.

Stern, R.A., Syme, E.C. and Lucas, S.B. 1995: Geochemistry of 1.9 Ga MORB- and OIB-like basalts from the Amisk collage, Flin Flon Belt, Canada: evidence for an intra-oceanic origin; Geochimica et Cosmochimica Acta, v. 59, no. 15, p. 3131–3154.

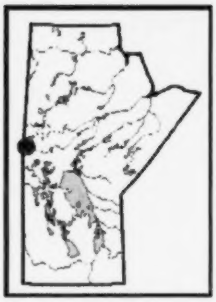
Syme, E.C. and Bailes, A.H. 1993: Flin Flon area geology; *in* New Perspectives on the Flin Flon–Snow Lake–Hanson Lake Belt from the NATMAP Shield Margin Project, Canadian Institute of Mining and Metallurgy, Field Trip 1 (Part 2) Guidebook.

Syme, E.C., Lucas, S.B. and Stern, R.A. 1999: Contrasting arc and MORB-like assemblages in the Paleoproterozoic Flin Flon Belt, Manitoba, and the role of intra-arc extension in localizing volcanic-hosted massive sulphide deposits; Canadian Journal of Earth Sciences, v. 36, no. 11, p. 1767–1788.

Theyer, P. 2001: Platinum group element investigations in the Flin Flon greenstone belt: McBratney Lake occurrence and Josland Lake intrusion (parts of NTS 63K/9, /13); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 33–39.

GS-12 PLATINUM GROUP ELEMENT INVESTIGATIONS IN THE FLIN FLON GREENSTONE BELT: PETROGRAPHY AND MINERALOGY OF THE MCBRATNEY LAKE PGE-AU OCCURRENCE (NTS 63K13), MANITOBA

by G. Olivo[1], P. Theyer and N. Bursztyn[1]



Olivo, G.R., Theyer, P. and Bursztyn, N., 2002: Platinum group element investigations in the Flin Flon greenstone belt: petrography and mineralogy of the McBratney Lake PGE-Au occurrence (NTS 63K13), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 94–99.

SUMMARY

The McBratney Lake PGE-Au occurrence is an example of hydrothermal PGE-Au mineralization, which is hosted by the mafic volcanic rocks of the Bear Lake basaltic andesite unit in the Flin Flon greenstone belt. This occurrence is characterized by extensive carbonate-chlorite-sulphide alteration and contains various platinum group minerals (PGM). They are, in order of abundance, borovskite (Pd_3SbTe_4), two unknown Pd telluride-antimonide minerals, sudburyite (PdSb), sperrylite ($PtAs_2$), temagamite (Pd_3HgTe_3) and merenskyite ($PdTe_2$). They commonly occur as inclusions in chalcopyrite, pyrite and carbonate, and are replaced by cobaltite-gersdorffite. Electrum (Au-Ag alloy) is also associated with the PGM and occurs included in chalcopyrite.

INTRODUCTION

The McBratney Lake PGE-Au occurrence, hosted by the mafic rocks of the Bear Lake Block in the Flin Flon greenstone belt, is located approximately 7 km east of the town of Flin Flon (Fig. GS-12-1a). This occurrence has been referred to as a 'contact-type' PGE occurrence, based mainly on field observations (Theyer, 2001); however, little is known about the alteration, precious metal mineralogy and paragenetic sequence of this occurrence. The purpose of this report is to summarize the findings of a preliminary investigation of the McBratney Lake PGE-Au occurrence, focusing on the petrography and mineralogy of the mineralized zones. The samples studied here were collected in the summer of 2001 in the stripped high-grade PGE-Au zone (up to 31 g/t Pd and 9 g/t Pt; Fort Knox Gold Resources Inc., press release, Aug. 13, 2001) of the McBratney Lake property (Fig. GS-12-1b).

GEOLOGY

Bear Lake Block

The McBratney Lake PGE-Au occurrence is hosted in the Bear Lake basaltic andesite, close to a gabbroic intrusive body (Theyer, 2001) that is interpreted to be related to the Wonderland gabbro, which is part of the Bear Lake Block (Bailes and Syme, 1989). This tectonic block is part of the 1.8 to 1.9 Ga Flin Flon greenstone belt (Syme et al., 1987; Gordon et al., 1989), which is composed of the following eleven units (from bottom to top; Bailes and Syme, 1989): Bear Lake basaltic andesite (3300 m thick), heterolithic breccia (150 m), Solodiuk Lake rhyolite (250 m), White Lake dacitic tuff (300 m), Little Spruce Lake andesitic lapilli tuff (350 m), mudstone and massive sulphide mineralization (25 m), Two Portage Lake ferrobasalt and rhyolite crystal tuff (200 m), Vick Lake andesitic tuff (900 m), dacite tuff (100 m) and intermediate tuff and breccia (30 m). These units form an east-facing homoclinal structure and are bounded to the west by the Inlet Arm Fault and to the east by the Northeast Arm Fault. In addition to the PGE-Au occurrences, the Bear Lake Block hosts two Cu-Zn massive sulphide deposits (Cuprus and White Lake mines) and a Au-rich Zn massive sulphide deposit (Westfield deposit).

Bear Lake basaltic andesite and Wonderland Lake gabbro

The Bear Lake basaltic andesite comprises aphyric to pyroxene- and plagioclase-phyric lava flows, breccias with pillow fragments, abundant synvolcanic dikes and sills, and very minor interflow tuff (Bailes and Syme,1989). In the summer of 2002, a geological survey was conducted in the vicinity of the McBratney Lake occurrence and drill cores that intercepted the mineralized zones were described in detail and sampled. Access to the core was provided by Hudson Bay–Anglo American and Fort Knox Gold Resources Inc. The following five distinct zones were documented in the Bear Lake basaltic andesite: 1) pillow basalt, with intense epidote alteration; 2) amygdaloidal basalt with epidote alteration; 3) breccia, composed mainly of pillow fragments; 4) medium-grained, mafic volcaniclastic rocks with fragments of plagioclase crystals in a Mg-chlorite matrix; and 5) fine-grained mafic volcaniclastic rocks with fragments

---

[1] Department of Geological Sciences and Geological Engineering, Queen's University, Bruce Wing–Miller Hall, Kingston, Ontario K7L 3N6

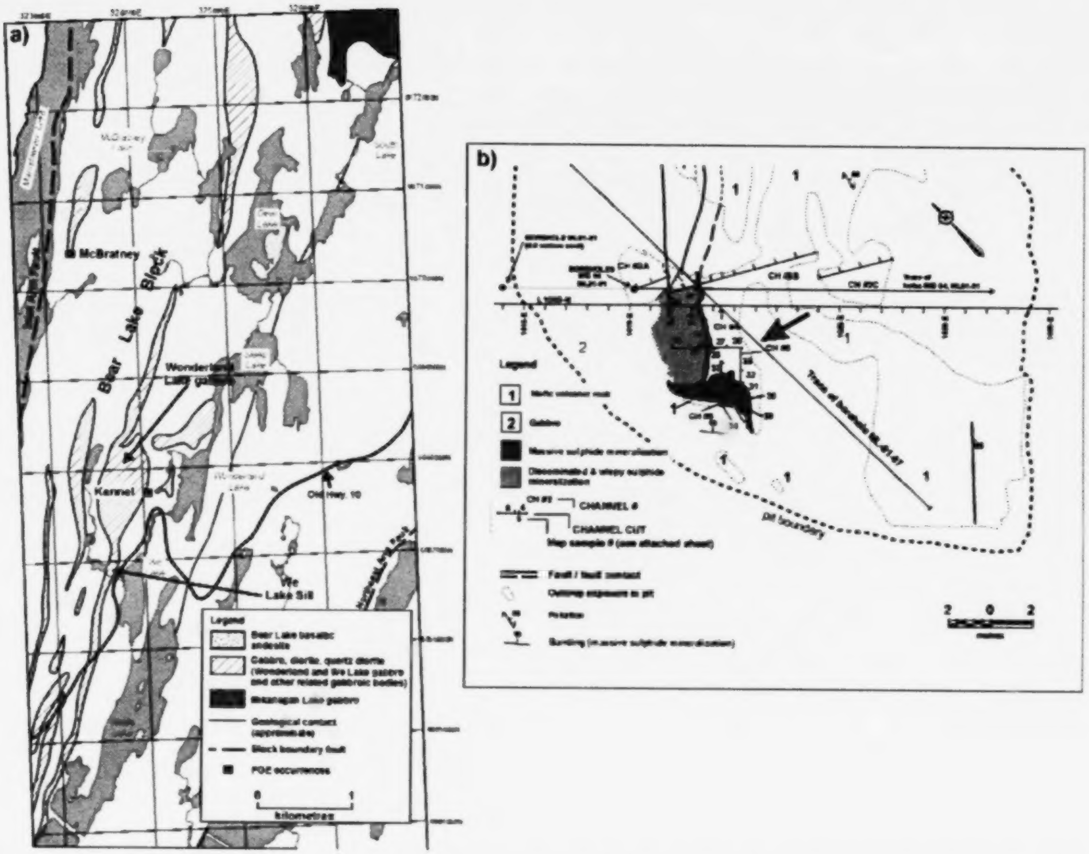


Figure GS-12-1: a) Simplified geological map of the west part of the Bear Lake Block, showing the location of the McBratney Lake PGE-Au occurrence (modified after Bailes and Syme, 1989; Theyer, 2001). b) Simplified geological map of the south part of the McBratney pit, showing locations of the studied samples (modified after Theyer, 2001).

of plagioclase crystals in a Fe-chlorite matrix. These rocks are deformed and, in the vicinity of the mineralization, intensively foliated and locally brecciated. Their contacts with gabbroic dikes and sills are tectonic, characterized by shear faults (Fig. GS-12-2a) with local intense veining. These gabbroic intrusions are tentatively correlated with the Wonderland Lake gabbro unit, which was described by Bailes and Syme (1989) as containing mainly gabbroic rocks in the western half of the intrusion and more evolved quartz diorite in the eastern part. They are also described by Theyer and Heine (GS-X31, this volume). In the field and in drill cores, various generations of the mafic dikes and sills are cut by irregular masses of leucocratic gabbro-diorite (Fig. GS-12-2b). Textures and structures observed in the field suggest that magma mixing was an important process during the formation of these gabbroic rocks. Near the Kennel occurrence (Fig. GS-12-1a), the gabbroic rocks contain fragmented layers of massive magnetite (Fig. GS-12-2c).

PETROGRAPHY AND MINERALOGY

Seven samples from channels #4 and #5 of the McBratney pit were selected for detailed petrographic and mineralogical investigations (*see* Fig. GS-12-1b for locations). The mineralized samples, which are hosted by the Bear Lake basaltic andesite, are layered and/or brecciated and cut by veinlets. They are composed mainly of sulphide minerals, cobaltite-gersdorffite, chlorite, carbonate, biotite and minor muscovite, plagioclase, magnetite, coloradoite, electrum and PGM. Plagioclase occurs as phenocrysts that are partially altered to chlorite or carbonate. Chlorite and carbonate commonly fill irregular veinlets or patches, and locally occupy corroded zones in plagioclase and sulphide minerals, or pseudomorphously replace a mafic phase. Some of the veinlets comprise alternating layers of chlorite and carbonate, indicating various episodes of open-space filling. Biotite laths are either associated with carbonate or included in sulphide minerals. Partially corroded magnetite euhedra occur within chalcopyrite and locally contain inclusions of PGM.

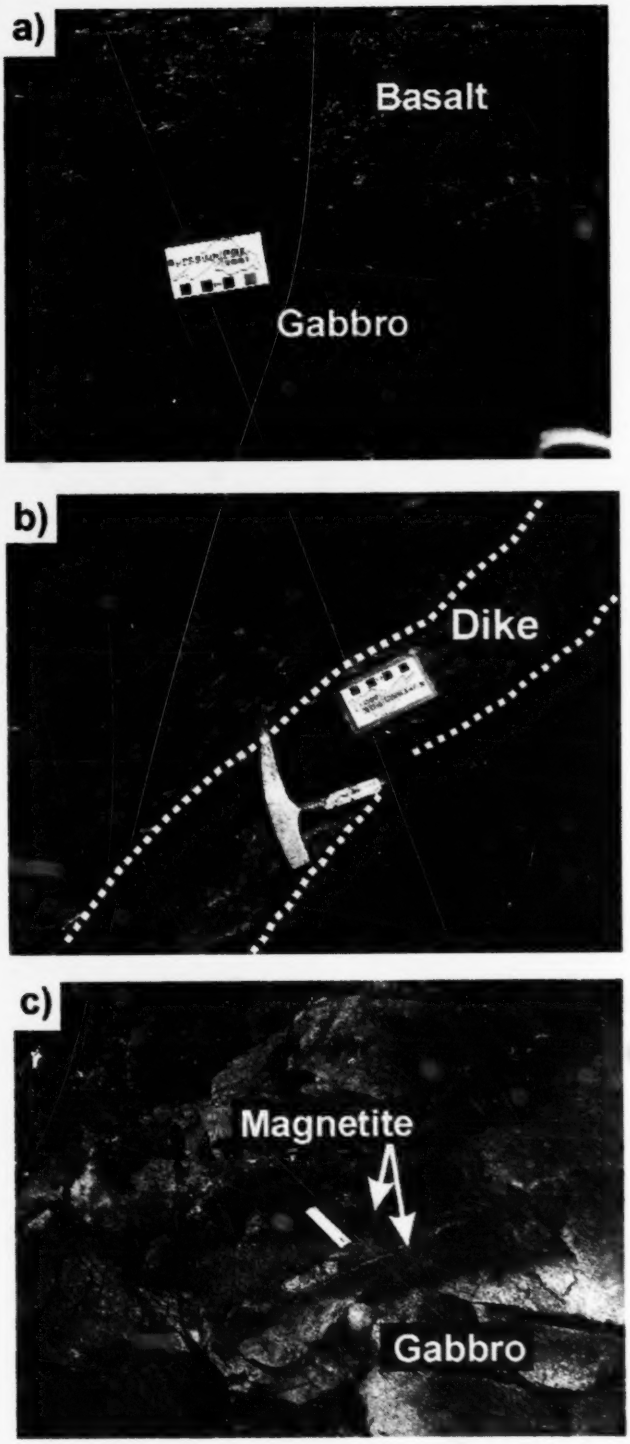

a)
Basalt
Gabbro
b)
Dike
c)
Magnetite
Gabbro

Figure GS-12-2: a) Contact between mafic dike of the Wonderland Lake gabbro and pillow basalt from the Bear Lake basaltic andesite. b) Fine-grained diabase dike cutting the main gabbroic unit of the Wonderland Lake gabbro. c) Magnetite layers in the Wonderland Lake gabbro.

The sulphide minerals are pentlandite, Ni-bearing pyrrhotite, pyrite, bravoite, marcasite, chalcopyrite, millerite, sphalerite and galena. Pentlandite is almost completed altered, forming boxworks. Pyrrhotite forms irregular masses and is commonly altered and replaced by pyrite and millerite. Pyrite occurs in fractured aggregates of cubic euhedra and is locally intergrown with bravoite and replaced by marcasite and cobaltite-gersdorffite. Chalcopyrite forms irregular patches and commonly fills embayments in the margins and fractures of pyrite and pyrrhotite. Sphalerite is very rare and occurs included in chalcopyrite, where it is spatially associated with electrum. Galena forms irregular grains and is commonly found in carbonate veinlets. Cobaltite-gersdorffite commonly replaces the Ni-, Fe- and Cu-bearing sulphide minerals, electrum and PGM. Coloradoite (HgTe) is rare and forms composite grains with other PGM. Electrum (20–30 wt% Ag) euhedra are included in chalcopyrite, where they are locally associated with sphalerite. Corroded electrum grains are commonly surrounded by cobaltite-gersdorffite.

The most common PGM are (Fig. GS-12-3) borovskite (Pd_3SbTe_4), sudburyite (PdSb) and two unknown minerals, whose optical properties and compositions differ from the Pd minerals reported in Cabri (2002). Sperrylite ($PtAs_2$), temagamite (Pd_3HgTe_3) and merenskyite ($PdTe_2$) are rare. Borovskite occurs as euhedral grains (up to 0.2 mm in diameter), commonly included in chalcopyrite and pyrite, and locally as composite grains with merenskyite, sperrylite and temagamite. Sudburyite (up to 0.2 mm) occurs as euhedral grains included in chalcopyrite or carbonate, or as corroded grains mantled by cobaltite-gersdorffite. Sperrylite (up to 30 µm) forms composite grains with borovskite and the unknown PGM. Merenskyite (up to 50 µm) is rare and occurs as composite grains with borovskite and temagamite, as free grains in corroded zones between chalcopyrite and cobaltite-gersdorffite, or included in magnetite. Temagamite (up to 50 µm) was found in composite grains with borovskite-merenskyite, or with one of the unknown PdSbTe phases. The mode of occurrence of the various PGM is shown in Figure GS-12-3, and their compositions are reported in Table GS-12-1.

DISCUSSION AND CONCLUSIONS

The petrographic and mineralogical data suggest that the McBratney Lake mineralization is hydrothermal and the major ore minerals are found in carbonate-chlorite veins or replacement zones in the Bear Lake basaltic andesite. Palladium forms mainly telluride-antimonide minerals; however, Pt forms arsenide minerals and Hg is commonly associated with the former. Most of the PGM and electrum precipitated contemporaneously with pyrite and/or chalcopyrite, which replace and fill veins in the mafic volcanic rocks. Sulphide minerals, PGM and electrum were later replaced by cobaltite-gersdorffite, which is one of the latest phases to precipitate. Curiously, Au is alloyed with Ag and its PGE content is lower than the microprobe detection limit. In other Pd-rich hydrothermal occurrences, Au commonly forms alloys with Pd (Olivo and Gauthier, 1994; Olivo et al., 1995; Olivo and Gammons, 1996; Olivo et al., 2001 and references therein).

Other aspects related to the geology and genesis of this hydrothermal PGE-Au occurrence are being investigated by Natalie Bursztyn and Gema Olivo, and include petrographic, mineralogical, geochemical and isotopic characterization of the host unit, the PGE-bearing sulphide lenses/veins and the barren ones, as well as a study of the hydrothermal fluids associated with this mineralization.

ACKNOWLEDGMENTS

The researchers would like to acknowledge the support of Hudson Bay Exploration and Development Co. Ltd. and Fort Knox Gold Resources Inc., for allowing access to their databases, sample archives and core-logging facilities, and for the valuable discussions with their staff. The Manitoba Geological Survey is acknowledged for its logistical support and hospitality at the former Centennial mine site.

REFERENCES

Bailes, A.H. and Syme, E.C. 1989: Geology of Flin Flon–White Lake area; Manitoba Energy and Mines, Geological Services, Geological Report GR87-1, 313 p. and 2 maps.

Cabri, L. J. 2002: The platinum group minerals; *in* The Geology, Geochemistry, Mineralogy and Mineral Beneficiation of Platinum group Elements; L. Cabri (ed.), Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 54, p. 483–506.

Gordon, T.M., Hunt, P.A., Bailes, A. and Syme, E.C. 1989: U-Pb zircon ages from the Flin Flon and Kisseynew belts, Manitoba: chronology of crust formation at an Early Proterozoic accretionary margin; *in* The Early Proterozoic Trans-Hudson Orogen: Lithotectonic Correlations and Evolution, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 177–200.

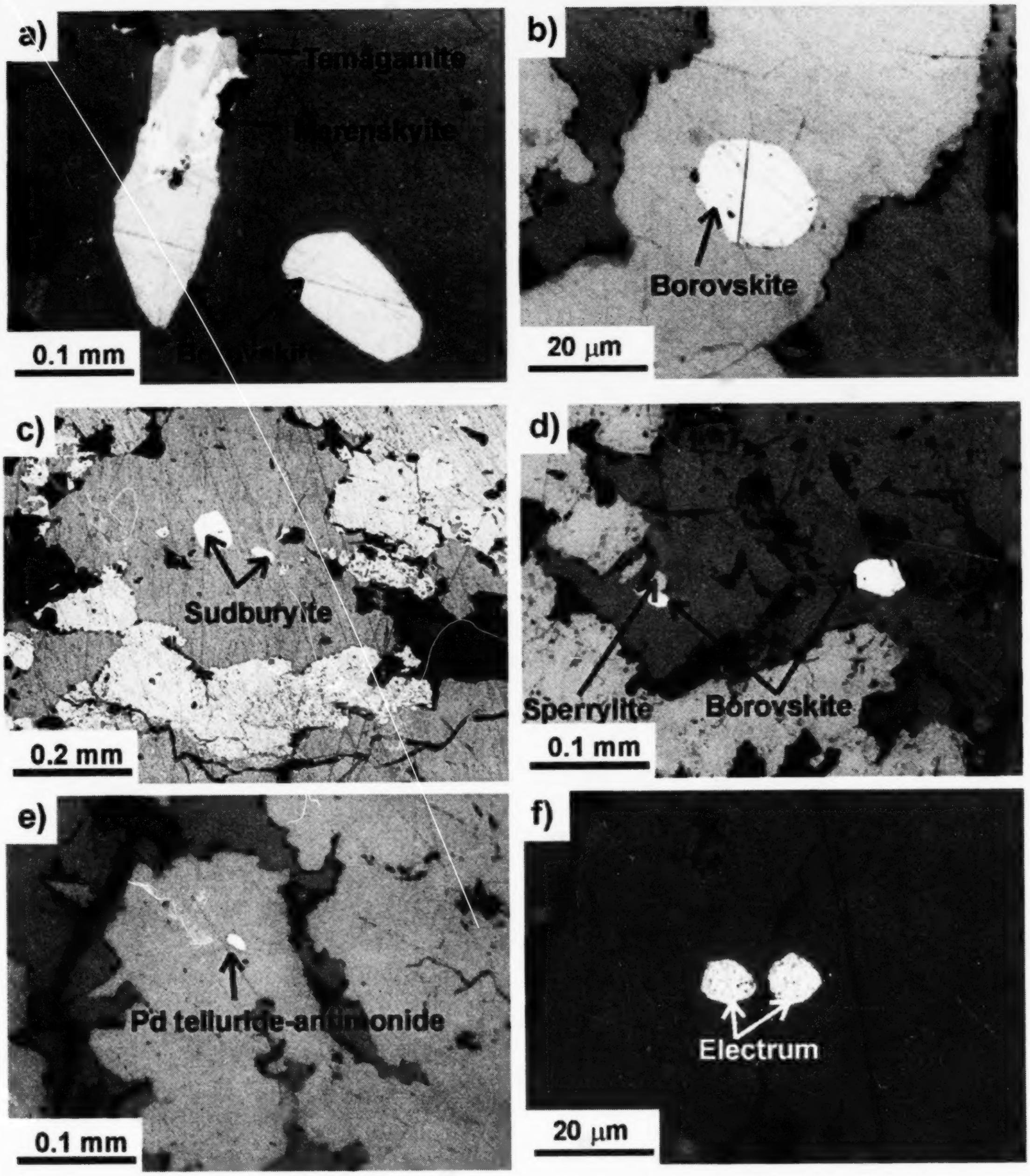

a)
Temagamite
Merenskyite
Borovskite
0.1 mm
b)
Borovskite
20 μm
c)
Sudburyite
0.2 mm
d)
Sperrylite
Borovskite
0.1 mm
e)
Pd telluride-antimonide
0.1 mm
f)
Electrum
20 μm

Figure GS-12-3: Platinum group minerals from the McBratney Lake PGE-Au occurrence: a) borovskite-temagamite-merenskyite composite grain (large grain) and borovskite euhedrum included in chalcopyrite; b) borovskite euhedrum included in pyrite; c) sudburyite euhedra included in chalcopyrite; d) borovskite-sperrylite composite grain included in chalcopyrite; e) unknown Pd telluride-antimonide mineral included in pyrite; and f) two electrum grains included in chalcopyrite.

Table GS-12-1: Composition of the platinum group minerals from the McBratney Lake PGE-Au occurrence.

Element	Borovskite (n=27)	Sudburyite (n=10)	Merenskyite (n=2)	Temagamite (n=3)	Sperrylite (n=8)	Unknown-1 (n=23)	Unknown-2 (n=11)
Pd	27.9–31.6	41.6–46.1	27.0–29.4	33.1–35.7	0.0–0.2	41.8–45.6	31.1-33.4
As	n.d.	n.d.	n.d	n.d	43.6–44.6	n.d.	0.2-0.3
Hg	n.d.	0.4–3.9	n.d	20.3–21.9	n.d.	0.6–1.7	n.d
Sb	13.5–14.2	44.3–52.4	0.8–4.6	n.d	n.d.	39.4–42.4	20.9-21.6
Pt	n.d.	n.d.	n.d.	n.d	54.3–55.6	0.0–0.1	n.d
Te	51.2-52.6	0.4–7.8	63.8–64.9	34.7–40.7	n.d.	10.1–15.2	42.5-43.7
Cu	n.d.	n.d.	n.d	n.d	0.0–0.1	n.d.	n.d
Ag	n.d.	n.d.	n.d	n.d	0.2–0.4	0.0–0.1	n.d
Ni	1.1–3.2	0.0–0.7	0.0–0.1	0.3–1.5	0.0–0.7	0.0–0.6	1.7-1.9
Bi	1.2–1.7	0.1-0.3	0.5–0.8	0.0–0.1	0.0–0.1	0.2–0.6	0.2-0.5
Co	0.0–0.5	n.d.	0.0–0.2	n.d.	n.d.	n.d.	n.d
Fe	0.1–1.7	0.1–1.2	0.4–1.9	0.6–0.8	0.5–1.7	0.0–1.2	0.1-1.3
Total	99.1–101.4	98.5–100.0	95.7–98.8	98.4–100.6	99.4–101.5	98.9–100.8	99.9-101.0

n.d., not detected

Olivo, G.R. and Gauthier, M. 1994: Palladian gold from the Cauê iron mine, Itabira District, Minas Gerais, Brazil; Mineralogical Magazine, v. 58, p. 579–587.

Olivo, G.R. and Gammons, C.H. 1996: Thermodynamic and textural evidence for at least two stages of Au-Pd mineralization at the Cauê iron mine, Itabira District, Brazil; Canadian Mineralogist, v. 34, p. 547–557.

Olivo, G.R., Gauthier, M., Bardoux, M., Leao de Sa, E., Fonseca, J.T.F. and Santana, F.C. 1995: Palladium-bearing gold deposits hosted by Proterozoic Lake Superior–type iron-formation at the Cauê iron mine, Itabira District, Southern Sao Francisco Craton, Brazil: geologic and structural controls; Economic Geology, v. 90, p. 118–134.

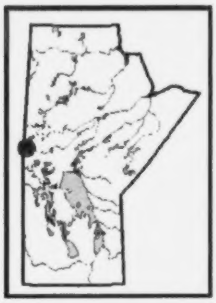
Olivo, G.R., Gauthier, M., Williams-Jones, A.E. and Levesque, M. 2001: The Au-Pd mineralization at the Conceição iron mine, Itabira District, Southern São Francisco Craton, Brazil: an example of a "jacutinga-type" deposit; Economic Geology, v. 96, p. 61–74.

Syme, E.C., Bailes, A.H., Gordon, T.M. and Hunt, P.A. 1987: U-Pb zircon geochronology in the Flin Flon: age of the Amisk volcanism; *in* Report of Field Activities 1987, Manitoba Energy and Mines, Minerals Division, p. 105–107.

Theyer, P. 2001: Platinum group element investigations in the Flin Flon greenstone belt: McBratney Lake occurrence and Josland Lake intrusion (parts of NTS 63K/9, /13); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 33–39.

GS-13 ACTIVITIES OF MANITOBA'S FLIN FLON REGIONAL OFFICE

by T.H. Heine



Heine, T.H. 2002: Activities of Manitoba's Flin Flon regional office, Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 100-101.

SUMMARY

The Flin Flon office provides assistance to the mineral-exploration and mining communities in the Flin Flon–Snow Lake region. These activities include

- recording new mineral claims,
- maintaining an up-to-date library of claim and land-status maps for the Province of Manitoba, and
- dealing with claim-status inquiries and accepting assessment-work submissions.

The present staff includes a Regional Geologist (Thomas Heine), a Resident Geologist (David Prouse) and a Mining Claims Inspector (Karen Costello). Since the last activities report, assistance was provided for several research projects undertaken in the region. An inventory of drill core stored at the Centennial mine site has been completed. The mine documentation project is proceeding with the addition of new samples from a number of now-closed mines in the region, including the Centennial, Cuprus, Coronation and Flexar mines. A representative ore and mine sequence rock-sample suite was collected from the Ruttan mine near Leaf Rapids prior to its closure in June 2002.

OFFICE RELOCATION

As a result of the closure of the Mining Recording office in The Pas and transfer of the files to Flin Flon in October 2002, the offices of the Department of Industry, Trade and Mines moved into larger accommodations at Suite 201 of the Barrow Provincial Building.

MINING RECORDING

Mining recording and related activities were the responsibility of the Regional and Resident geologists until early June 2002. At this time, the Mining Claims Inspector resumed her position in Flin Flon. As part of the function of this office, an up-to-date collection of claim and land-status maps for the Province of Manitoba is maintained for public reference. Other responsibilities of the Mining Recording office include the recording of applications for new claims, casual quarry permits and prospecting licenses, and accepting other applications and submissions that fall under the terms of the Mines Act. Staff of the Flin Flon office will prepare reports summarizing the status and history of specific claims on request.

EXPLORATION ASSISTANCE

The main function of the Flin Flon office is to provide assistance to the mining and mineral-exploration community and the public interested in the geology of the region. Access to the Precambrian Drill Core libraries in The Pas, Thompson and Lynn Lake is arranged through this office. A secure exterior storage area adjacent to the Centennial core-viewing facility is available for clients who wish to protect their core from vandalism or loss. Up-to-date inventories of the northern libraries and the Centennial site have been made (Prouse, GS-39, this volume).

Property visits, examinations, recommendations for further work and technical advice were provided to several clients.

Logistical and technical support was provided to several summer field projects undertaken in the region, including the federal-provincial Flin Flon Targeted Geoscience Initiative (TGI) and projects of the Saskatchewan Geological Survey and the Manitoba Geological Survey.

Technical support for the Green Project, a local initiative to ameliorate the acidic soil conditions and promote plant growth in areas affected by SO_2 discharge from the Flin Flon smelter, continued to be provided by this office. Volunteers continued to spread crushed dolomitic limestone on selected areas. Results of this project are encouraging, with increased vegetation growth noted in several treated areas. Plant species that were absent from affected areas also appear to be re-establishing themselves.

Participation in the Northwest Region Woodland Caribou Management and Research Committee continued.

REPORTS

Text and figures for the *Mineral Deposit Series* report for Iskwasum Lake (NTS area 63K10) have been completed, with the report to be released in January 2003. The report for Elbow Lake (NTS area 63K15) has also been completed, with final editing of figures and map in progress. It is anticipated that this report will be also be released early in 2003.

The activities of the mining and mineral-exploration communities within Manitoba are actively monitored, and summary reports are prepared for both internal use and external publication.

Manitoba Conservation approached this office seeking input for a problem that has arisen in the Schist Lake area. Parts of Schist Lake, particularly Northeast Arm and Inlet Arm, show increased total phosphorus (ΣP) levels, to the extent that they are subject to algal blooms. Residents along Inlet Arm have expressed some concern about this situation because of the increased turbidity of the water, and because it tends to clog water filters for those who obtain water from the lake. The only source of phosphorus in this area appears to be the rock sequence west-northwest of Northeast Arm. A report outlining the problem and suggested course of investigations to determine the source of the phosphorus has been prepared (Heine, 2002) and given to Darcy Chrisp, the local Environment Officer.

MINE DOCUMENTATION PROJECT

The ongoing mine-documentation project, outlined previously (Heine and Prouse, 2000, 2001), continues to progress. Hudson Bay Exploration and Development Co. Ltd. continued their support for this project. The collection of representative ore samples obtained last year from Neil Provins (Falconbridge (Australia) Pty. Limited) has been slabbed, polished and added to the Flin Flon archive suite.

A representative sample suite of the Ruttan mine was collected in February 2002 for inclusion in the Flin Flon reference collection. One hundred and fourteen ore and associated rock samples were collected from the underground workings and are currently stored at the Centennial core-viewing facility. The underground geological plans were supplied in digital format by Hudson Bay Mining and Smelting Co., Limited, and are included in the archive collection.

The Flin Flon Station Museum is a popular stop for residents and visitors to our community. It was decided, in consultation with the museum board, that it would be worthwhile to install a display outlining the geology of the area and describing some of the deposits in the region. This will include an integral display of rock and ore samples, both from the museum and from the Flin Flon reference collection. The samples from the reference collection will be loaned to the museum. This exhibit will be installed in the spring of 2003, on completion of the display case and printed materials.

REFERENCES

Heine, T.H. 2002: Phosphorus in Schist Lake; unpublished report prepared for Manitoba Conservation.

Heine, T.H. and Prouse, D.E. 2000: Activities of the Flin Flon regional office; *in* Report of Activities 2000, Manitoba Energy and Mines, Manitoba Geological Survey, p. 12.

Heine, T.H. and Prouse, D.E. 2001: Activities of the Flin Flon regional office; *in* Report of Activities 2001, Manitoba Energy and Mines, Manitoba Geological Survey, p. 45–46.

GS-14 TECTONOSTRATIGRAPHY, SM-ND ISOTOPE AND U-PB AGE DATA OF THE THOMPSON NICKEL BELT AND KISSEYNEW NORTH AND EAST MARGINS (NTS 63J, 63P, 63Q, 64A, 64B), MANITOBA

by H.V Zwanzig and Ch.O. Böhm[1]

Zwanzig, H.V. and Böhm, Ch.O. 2002: Tectonostratigraphy, Sm-Nd isotope and U-Pb age data of the Thompson Nickel Belt and Kisseynew north and east margins (NTS 63J, 63P, 63Q, 64A, 64B), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 102-114.

SUMMARY

This report demonstrates an application of combined remapping, core relogging and isotopic dating techniques to unravel the complex tectonostratigraphy across the Superior Boundary Zone. The work aims to clarify the structure, mineral potential and extent of the Thompson Nickel Belt and the adjacent Kisseynew Domain in north-central Manitoba. The Sm-Nd isotope methods and U-Pb dating applied to these Precambrian medium- to high-grade gneiss units provide a clear distinction between 1) Neoarchean basement, 2) cover rocks (hosting nickel deposits), 3) juvenile Paleoproterozoic paragneiss (probably thrust in from the Kisseynew Domain), and 4) a Mesoarchean gneiss complex (the likely host of important precious metal prospects). A summary of preliminary results is presented from Pearson Lake, the Mel zone and Setting Lake. The continuing work encompasses Rock Lake, Assean Lake, Leftrook and Harding lakes, and various locations in the Thompson Nickel Belt.

INTRODUCTION

The key to rigorous mapping of Precambrian gneiss in north-central Manitoba lies in establishing unique stratigraphic sequences and determining their ages. Mapping and core logging have been combined with Sm-Nd isotope and U-Pb age data to test stratigraphic, tectonic and metallogenic models (Zwanzig et. al., 2001). The project area currently extends along the boundary between the Kisseynew Domain (KD) and Thompson Nickel Belt (TNB) in the southeast, and the Lynn Lake–Leaf Rapids domains and Assean Lake crustal complex (Böhm et al., 2002) in the north (Fig. GS-14-1). Because outcrop is limited in large parts of the area, surface mapping was combined with relogging of company-owned drill core (Inco Technical Services Ltd., Nuinsco Resources Limited, Hudson Bay Exploration and Development Co. Ltd. and Strider Resources Ltd.). This collaborative work has led to the recognition of previously distinguished stratigraphic sequences, which include the Neoarchean basement gneiss and the Paleoproterozoic Ospwagan Group in the TNB, the Mesoarchean Assean Lake crustal complex in the northeast, and the Paleoproterozoic Burntwood, Sickle and Grass River groups in the KD. Many of these assemblages contain similar looking orthogneiss and migmatitic greywacke-gneiss or semipelite derived from turbidite to marine shelf or basin deposits, units that cannot be distinguished using petrographic analysis alone. The ages (T_{CR} Nd model and U-Pb igneous, metamorphic and detrital zircon ages) of these units are critical in establishing a geological and therefore metallogenic framework for the region. Major- and trace-element geochemistry and petrographic work provide additional data to distinguish the various units.

This report provides a current geological overview of the project area and delineates the areas of new mapping, core logging and sampling. Also included is a preliminary summary of tectonostratigraphy and the geochronology determined from samples collected during 2001 along the northern extension of the TNB (Mel zone), from further to the northeast (Pearson Lake) and from earlier sampling in the south (Setting Lake). During the summer of 2002, mapping and surface sampling were carried out on Leftrook and Harding lakes, 60 km northwest of Thompson. This ongoing work is expected to provide petrographic and isotopic data for stratigraphic units typical of the north flank of the KD. Drill core was relogged and samples collected from five sites along the TNB and possibly beyond its northern extension. These sites are, from southwest to northeast,

1) Soab Lake area,

2) Tailor River (Kipper),

3) Birchtree Mine area,

4) Rock Lake (50 km northeast of Thompson), and

5) Assean Lake (Hunter and Tex claims).

The new samples from these areas are expected to provide petrographic, geochemical, isotopic and geochronological data for the Paleoproterozoic rocks and the Archean gneiss in the TNB and the northern part of the Superior Boundary

---

[1] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3

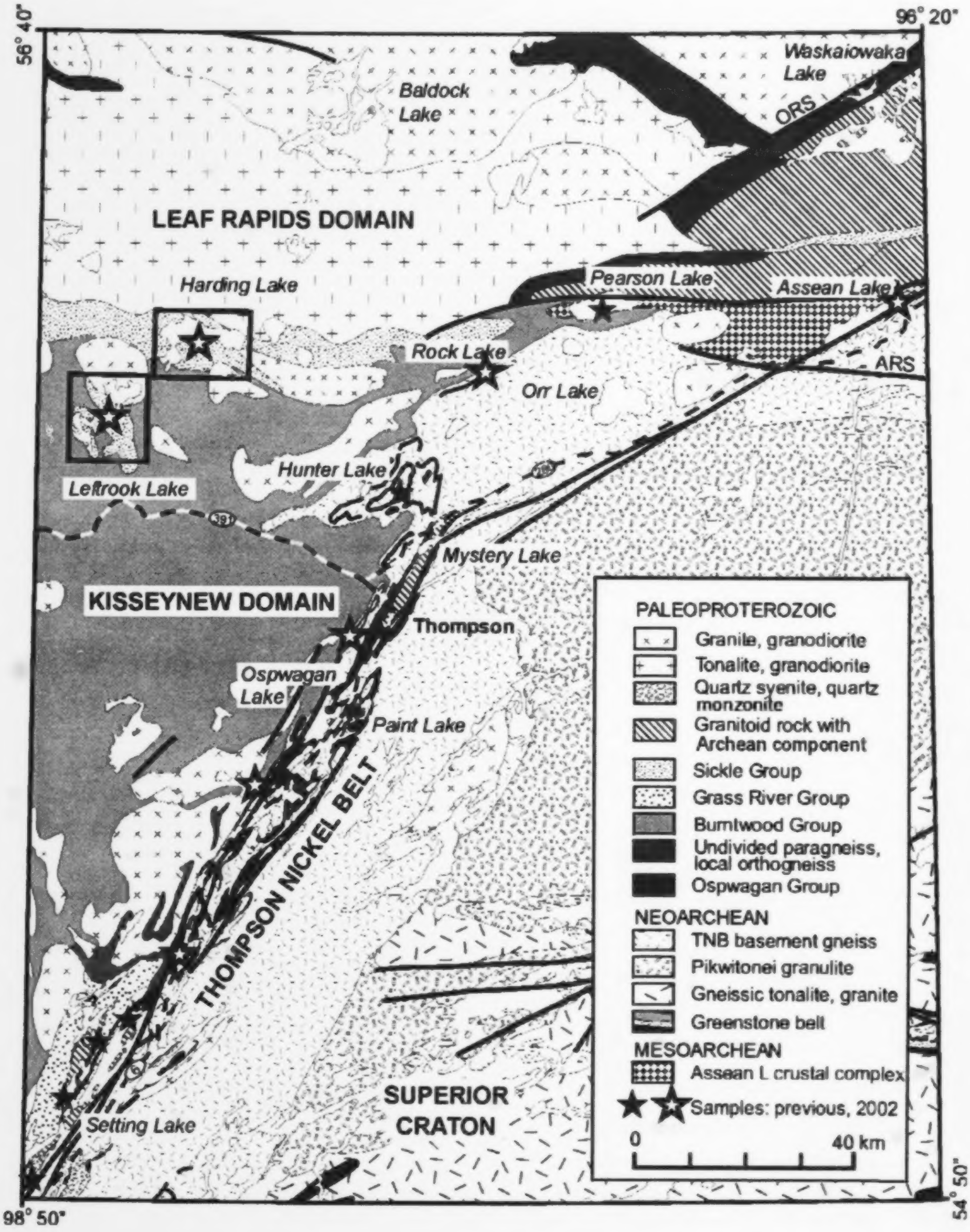

56° 40'
96° 20'
Waskaiowaka Lake
Baldock Lake
ORS
LEAF RAPIDS DOMAIN
Harding Lake
Pearson Lake
Assean Lake
Rock Lake
ARS
Orr Lake
Hunter Lake
Leftrook Lake
391
Mystery Lake
KISSEYNEW DOMAIN
Thompson
Ospwagan Lake
Paint Lake
THOMPSON NICKEL BELT
Setting Lake
SUPERIOR CRATON
PALEOPROTEROZOIC
Granite, granodiorite
Tonalite, granodiorite
Quartz syenite, quartz monzonite
Granitoid rock with Archean component
Sickle Group
Grass River Group
Burntwood Group
Undivided paragneiss, local orthogneiss
Ospwagan Group
NEOARCHEAN
TNB basement gneiss
Pikwitonei granulite
Gneissic tonalite, granite
Greenstone belt
MESOARCHEAN
Assean L crustal complex
Samples: previous, 2002
0
40 km
98° 50'
54° 50'

Figure GS-14-1: Sample location map and simplified geology of the Thompson Nickel Belt (TNB), part of the Kisseynew Domain, the margins of the Lynn Lake–Leaf Rapids domains, and the Assean Lake crustal complex. The distribution of the Ospwagan Group in the Hunter Lake–Rock Lake area is schematic and speculative; the full extent of the TNB is unknown. Abbreviations: ORS, Owl River Shear Zone; ARS, Aiken River Shear Zone.

Zone. The dataset will augment the results of the work done in the Mel zone and at Pearson Lake in 2001. The work is intended to delineate the extent of the various tectonic domains more fully and to help resolve stratigraphic and structural problems where units are interleaved at their boundaries.

GEOLOGICAL OVERVIEW

The region between Setting Lake, Assean Lake and Leftrook Lake includes the collisional boundary zone of the Superior Craton with the internal zone of Trans-Hudson Orogen. The region is dominated by the TNB, a northeast-trending belt of migmatitic orthogneiss that is unconformably overlain by the Paleoproterozoic Ospwagan Group (Fig. GS-14-1). North of Mystery Lake, the shape and extent of the TNB is largely speculative. In the main part of the belt, the Ospwagan Group is recognized as a distinctive succession of platform (rift-drift) metasedimentary formations with rift-related volcanic rocks at the top (Fig. GS-14-2). It is intruded by ca. 1.88–1.86 Ga ultramafic-mafic sills and dikes and is host to the largest nickel deposits in Manitoba. The Ospwagan Group, which was affected by early nappe tectonics and amphibolite-facies metamorphism, occupies long, narrow, northeast-trending folds at the northwest margin of the basement-dominated TNB (Bleeker, 1990). The basement gneiss grades into the Pikwitonei granulite gneiss to the southeast. In fact, much of the TNB basement gneiss was derived from the granulite by retrogression and structural overprinting along the Superior Boundary Zone, which, in Manitoba, is the southeastern external zone of the Trans-Hudson Orogen.

In the northwest, the TNB is bounded by younger Paleoproterozoic juvenile gneisses (Burntwood Group, Grass River Group and Proterozoic intrusions) in the KD, where they form part of the internal zone of Trans-Hudson Orogen. The Burntwood and Grass River groups are marine (turbidite) and nonmarine (fluvial-alluvial) deposits that were probably formed during the early stages of collision between the internal zone and the Superior Craton (Zwanzig, 1998). A syncollisional conglomeratic unit in the Grass River Group is interpreted to lie unconformably on the upper unit of basalt in the Ospwagan Group along the northwest shore of Setting Lake (Zwanzig, 1998). Previously, the entire northwest contact of the TNB was considered to be a fault (Bleeker, 1990). However, aeromagnetic trends, exploration

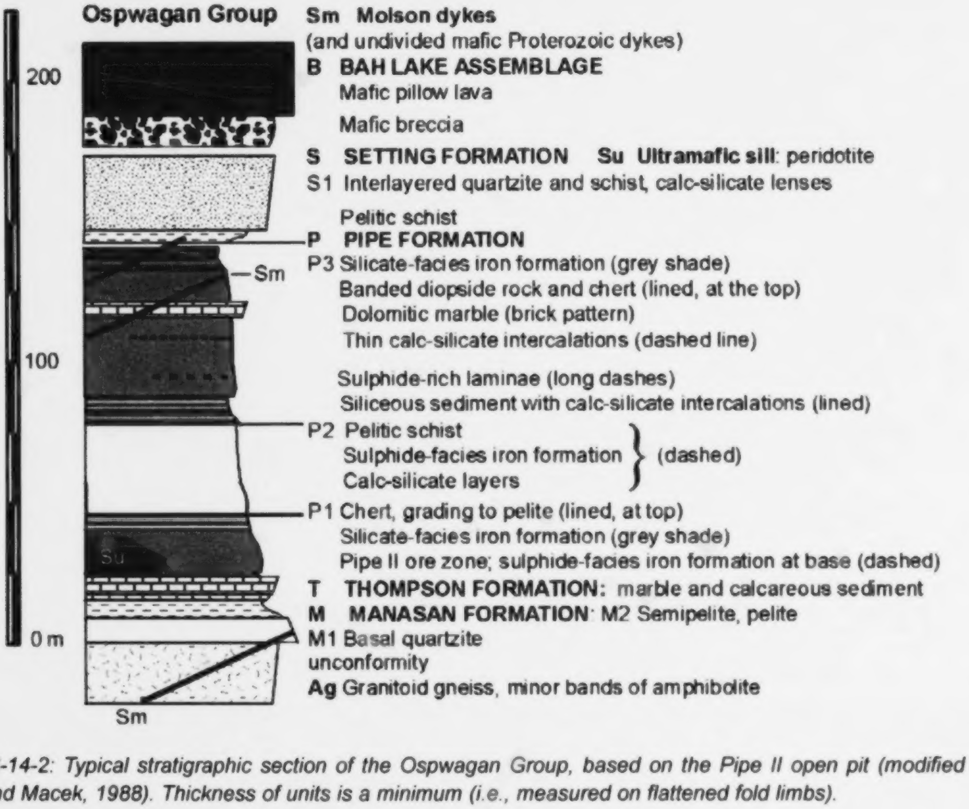

Ospwagan Group
200
100
0 m
Su
Sm
Sm
Sm Molson dykes
(and undivided mafic Proterozoic dykes)
B BAH LAKE ASSEMBLAGE
Mafic pillow lava
Mafic breccia
S SETTING FORMATION Su Ultramafic sill: peridotite
S1 Interlayered quartzite and schist, calc-silicate lenses
Pelitic schist
P PIPE FORMATION
P3 Silicate-facies iron formation (grey shade)
Banded diopside rock and chert (lined, at the top)
Dolomitic marble (brick pattern)
Thin calc-silicate intercalations (dashed line)
Sulphide-rich laminae (long dashes)
Siliceous sediment with calc-silicate intercalations (lined)
P2 Pelitic schist
Sulphide-facies iron formation
Calc-silicate layers
(dashed)
P1 Chert, grading to pelite (lined, at top)
Silicate-facies iron formation (grey shade)
Pipe II ore zone; sulphide-facies iron formation at base (dashed)
T THOMPSON FORMATION: marble and calcareous sediment
M MANASAN FORMATION: M2 Semipelite, pelite
M1 Basal quartzite
unconformity
Ag Granitoid gneiss, minor bands of amphibolite

Figure GS-14-2: Typical stratigraphic section of the Ospwagan Group, based on the Pipe II open pit (modified after Bleeker and Macek, 1988). Thickness of units is a minimum (i.e., measured on flattened fold limbs).

drill core and new structural mapping indicate that many faults and mylonite zones are relatively young and some cut northeast across the northern extension of the TNB (Fig. GS-14-1). Moreover, previously unpublished Sm-Nd isotope data suggest that granites within the eastern margin of the KD were contaminated by Archean crust. They may have been locally derived completely from Archean rocks and are now structurally interleaved with the juvenile Proterozoic units. Thus, the collisional boundary zone involves depositional contacts and structural contacts that were refolded and faulted during protracted deformation, and injected by various crust- to mantle-derived melts.

In the west, at Leftrook and Harding lakes, paragneiss and local amphibolite units form a succession typical of the north flank of the KD. They are mapped as greywacke-migmatite, similar to the Burntwood Group, and arkosic gneiss, equivalent to the Sickle Group exposed in the southern part of the Lynn Lake Domain (Corkery and Lenton, 1980). These rocks have the potential to provide an important stratigraphic section, with geochronological and Sm-Nd isotopic data, for the presumably juvenile rocks in the northern KD.

At Assean Lake, an ancient (Mesoarchean) crustal complex and prominent shear zones mark the margin of the Superior Craton. This complex was previously considered to be Proterozoic (Corkery and Lenton, 1980), but isotope and geochronological studies by Böhm et al. (2000, 2002) revealed Mesoarchean ages for felsic magmatism and greywacke-gneiss, with the latter containing ca. 3.2 to 3.9 Ga detrital zircons. Units of amphibolite and iron formation were also interpreted to be part of the Assean Lake crustal complex by Böhm et al. (2000). Mesoarchean ages to the south, along the Aiken River Shear Zone (Böhm et al., 2000 and unpublished data), suggest that the ancient crust is structurally interleaved with the Neoarchean, Superior-type gneiss and that the full extent of Mesoarchean crust along the Superior Boundary Zone is unknown. Predominantly Archean Nd model ages for orthogneiss between Assean Lake and the Owl River Shear Zone, further to the north, indicate the presence of mixed gneiss and variably contaminated plutons (Böhm et al., 2002). The orthogneiss was previously considered to represent simple Proterozoic intrusions and minor paragneiss of the Trans-Hudson internal zone (Leaf Rapids Domain). The convergence of the major shear zones and crustal elements is located at Pearson Lake and may make this area particularly important for a tectonic interpretation of the collisional boundary zone.

OBJECTIVES AND METHODOLOGY

Mapping

Surface mapping was carried out from fly-in camps on Leftrook and Harding lakes. Outcrop examination and sampling were restricted to shoreline exposures. Sample sets were collected for petrographic work on all units, and the most typical, least-veined varieties were collected and trimmed for geochemical and Sm-Nd isotopic studies. A limited set of predominantly intrusive rocks was collected as fresh broken samples of 15 kg or greater for U-Pb dating (zircon, monazite, sphene). The purpose of this work is to determine the age and test the validity of the stratigraphic sequence of sedimentary units established by Corkery and Lenton (1980) along the northern margin of the KD. The resulting geochronological and geochemical database will serve as a reference for a comparison with similar units that are structurally intercalated at, or adjoining, the margin of the TNB. The data are expected to help identify lithotectonic units in the blocks of complex, mixed gneiss.

Additional surface samples for U-Pb dating and Sm-Nd isotope work were collected on Fish Lake (west of Setting Lake), 100 km southwest of Thompson. These samples may verify preliminary Nd model ages, given in this report, that suggest interleaving of Archean- and Proterozoic-derived gneissic units in an area that was previously considered to contain only juvenile Proterozoic rocks.

Core logging

Much of the bedrock, particularly the sedimentary units in the TNB and northeastern part of the KD, are covered by lakes and muskeg. Access to mineral exploration drill core is therefore essential to reinterpreting these areas. At present, five exploration companies are collaborating with the Manitoba Geological Survey (MGS) and the University of Alberta Radiogenic Isotope Facility by providing critical company-owned core, drill logs, location data, funding and/or other support. Core is laid out in the company yard or at the MGS storage site, contacts are marked and units are described and sampled. Particular attention is given to distinctive units (e.g., marble or basal quartzite) and contacts that may be faults or unconformities. Stratigraphic successions are then compared to type sections in the TNB (e.g., Bleeker and Macek, 1988; Fig. GS-14-2) or assemblages in the KD (e.g., Corkery and Lenton, 1980) or elsewhere (e.g., Böhm, 1997; Böhm et al., 2002). Petrographic and geochemical studies carried out on core samples provide a database for comparing core in different areas. Radiometric dating can yield rigorous constraints for different tectonic units with similar appearance.

Sm-Nd isotope methods

The various units of orthogneiss and paragneiss along the Superior Boundary Zone and in the adjacent KD have yielded a wide range of ages that are not apparent from mapping and petrographic work. The Sm-Nd isotope methods provide a convenient technique of distinguishing the major tectonic assemblages at lower expense than precision U-Pb geochronology. However, these methods do not yield simple ages and may require a discussion of their application, interpretation and limitations, as provided in this section of the report.

The Sm-Nd isotope methods are useful in establishing the crustal evolution of Precambrian terrains such as the western Superior Province and the Trans-Hudson Orogen in Manitoba. Radiogenic isotopes can either be used for dating (e.g., U-Pb zircon dating) or, in the context of geochemistry, to identify provenance and study petrogenetic processes (e.g., Rb-Sr and Sm-Nd isotope methods). Since the different elements used in the isotope studies vary in their chemical and physical properties, individual isotope systems vary in their sensitivity to particular petrological processes. Samarium and neodymium — both being rare earth elements (REE) — have very similar chemical and physical characteristics. Rubidium and strontium, in contrast, are geochemically distinct, incompatible trace elements that are commonly fractionated by secondary processes (e.g., tectonometamorphic processes, fluid-rock interaction). Rubidium-strontium isotope data for metamorphic rocks are therefore rarely useful for constraining crust formation ages. Samarium and neodymium, on the other hand, are compatible trace elements (preferentially enriched in the mineral phases), have small bulk partition coefficients for most petrogenetic processes and are relatively immobile, even at higher metamorphic grade. Thus, the Sm-Nd whole-rock technique can be used in determining crust formation ages. However, relatively small variations in the Sm/Nd ratio are common in cogenetic gneissic rock types and therefore limit the time resolution of the Sm-Nd isotope system. For medium- and high-grade gneisses, crust formation ages are protolith ages and approximately represented by Nd model ages.

A model age is a measure of the length of time a rock has been separated from the mantle from which it was originally derived. A Nd model age can be calculated for an individual rock (bulk-rock sample) from a single pair of parent-daughter isotopic ratios (^{147}Sm/^{144}Nd and ^{143}Nd/^{144}Nd), and Nd model ages for the continental crust are usually calculated with reference to the depleted mantle (DM) reservoir. The two most commonly used models for depleted mantle evolution and the respective Nd model ages are by DePaolo (1981; T_{DM} Nd = depleted mantle separation Nd model age) and Goldstein et al. (1984; T_{CR} Nd = crustal residence Nd model age), with the latter being used here. Three assumptions form the basis of the Nd model age calculation:

1) The isotopic evolution of the reservoir from which the rock was originally derived (commonly mantle) is known.

2) The Sm-Nd isotopic composition of the rock has not been modified by fractionation or alteration after its separation from the mantle source.

3) The rock formed from the mantle in a single event.

For medium- and high-grade gneisses, these assumptions are not always fully applicable or reconstructable, as illustrated in Figure GS-14-3. Model ages must therefore be interpreted with care.

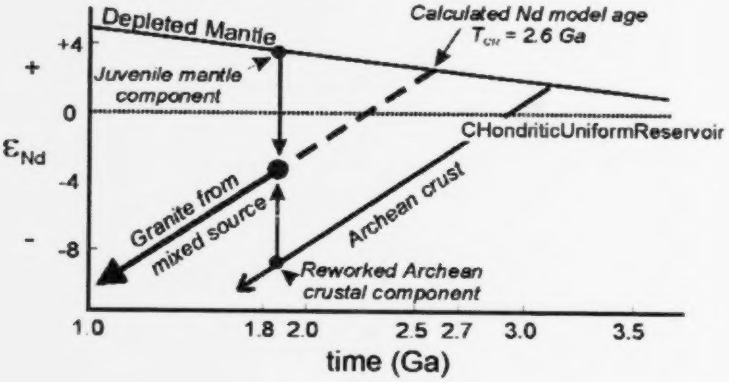
In order to discuss the common use of Nd model ages and the Nd isotopic composition of an analyzed bulk-rock sample, Figure GS-14-3 illustrates the Nd isotopic evolution plotted against time (in billion years) for depleted mantle and continental crust (*see* DePaolo, 1988). The Nd isotopic evolution, ^{143}Nd/^{144}Nd, is expressed as epsilon units, where

$\varepsilon_{Nd,t} = ((^{143}Nd/^{144}Nd_{initial}/^{143}Nd/^{144}Nd_{CHUR,t}) - 1) \times 10^4$

Relative to CHUR (chondritic uniform reservoir = bulk Earth composition), the depleted mantle shows increasing ^{143}Nd/^{144}Nd (increasingly positive ε values) with time, whereas the continental crust extracted from the mantle shows increasingly negative ε values with time.

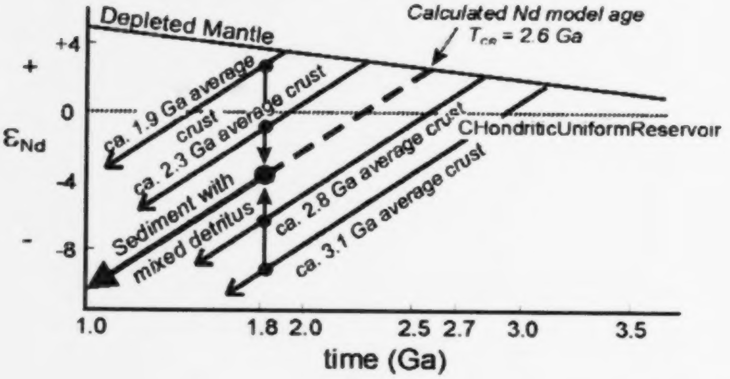
In Figure GS-14-3 (Example 1), a granite formed at 1.87 Ga from a mixture of juvenile, mantle-derived material and from Archean crust with an average protolith age of ca. 3.1 Ga. The calculated Nd model age of the granite sample is ca. 2.6 Ga, reflecting neither the crystallization age of the granite nor the age of the crustal source but that of the mixed source materials. It is important to note that the Nd model age of the granite sample can be calculated without knowing the crystallization age of the granite, the latter being commonly determined by U-Pb zircon dating methods. Knowing the age of the granite, however, the Nd isotopic evolution can be used to estimate the degree of involvement of older crust (inheritance or contamination), and the Nd model age represents a minimum protolith age.

In Figure GS-14-3 (Example 2), a sediment formed at ca.1.83 Ga from various source rocks with average residence ages of ca. 1.9, 2.3, 2.8 and 3.1 Ga. The Sm-Nd isotope analysis of the sedimentary sample yields a Nd model age of ca. 2.6 Ga. In this case, the Nd model age represents an estimate of the average provenance of the sediment. Complementary methods, such as U-Pb detrital zircon studies, can then be used to unravel the exact ages and proportions of source rocks involved.



Example 1: 1.87 Ga granite with a Nd model age of 2.6 Ga and ε_{Nd} = -4 (at 1.87 Ga)

Depleted Mantle
Calculated Nd model age
T_{CR} = 2.6 Ga
Juvenile mantle component
CHondriticUniformReservoir
Granite from mixed source
Archean crust
Reworked Archean crustal component
+4
+
0
ε_{Nd}
-4
-
-8
1.0
1.8
2.0
2.5
2.7
3.0
3.5
time (Ga)



Example 2: 1.83 Ga sedimentary rock with a Nd model age of 2.6 Ga and ε_{Nd}= -4 (at 1.83 Ga)

Depleted Mantle
Calculated Nd model age
T_{CR} = 2.6 Ga
ca. 1.9 Ga average crust
ca. 2.3 Ga average crust
Sediment with mixed detritus
ca. 2.8 Ga average crust
ca. 3.1 Ga average crust
CHondriticUniformReservoir
+4
+
0
ε_{Nd}
-4
-
-8
1.0
1.8
2.0
2.5
2.7
3.0
3.5
time (Ga)

Figure GS-14-3: Neodymium isotopic evolution with time, for depleted mantle and Precambrian continental crust (granite and sedimentary rock examples; see text for explanations).

In summary, the Sm-Nd isotope method represents a relatively rapid and inexpensive technique that is most successfully applied in the reconnaissance of Precambrian metamorphic terrains. The method has the potential to yield the protolith history of old high-grade gneisses and to distinguish between Archean and Proterozoic crust. As such, Nd isotopic mapping works best on a regional scale by comparing Nd model ages of felsic meta-igneous and metasedimentary rocks of similar composition across major crustal sutures, such as the Superior Boundary, Assean Lake and Aiken River deformation zones along the northwestern margin of the Superior Province (Fig. GS-14-1).

PRELIMINARY RESULTS

Pearson Lake

The geotectonic position of Pearson Lake is important for at least two reasons:

1) The northeast-trending Superior Boundary Zone and Owl River Shear Zone, which possibly separate mixed Archean and Proterozoic crust from dominantly Proterozoic crust along the northwestern margin of the Superior craton, meet in the Pearson Lake area (Fig. GS-14-1).

2) The northern extension of the Thompson Nickel Belt could be located along this margin.

A dominant granodiorite orthogneiss unit has been identified and dated at Pearson Lake (e.g., Zwanzig et al., 2001). Samarium-neodymium isotope analysis of the granodiorite gneiss yields a crustal residence (T_{CR}) Nd model age of ca. 3.3 Ga and current ε_{Nd} of approximately –39, clearly indicating the antiquity of the granodiorite gneiss precursor. Based on our U-Pb zircon dating, the crystallization age of the granodiorite gneiss is 3185 ± 7 Ma, similar to orthogneiss in the ancient Assean Lake crustal complex (e.g., Böhm et al, 2002). The granodiorite orthogneiss at Pearson Lake was metamorphosed at 1782.6 ± 1.1 Ma (metamorphic zircon), and separates paragneiss on the north shore from migmatized metagreywacke on the south shore. Results from Sm-Nd isotope analysis show that these paragneiss units are not related to each other. The southern metagreywacke yielded a ca 2.2 Ga T_{CR} Nd model age and ε_{Nd} at 1.8 Ga of approximately +2, which suggests that this metagreywacke dominantly or entirely consists of source rocks that are less than 2.0 Ga, similar to Burntwood Group metasedimentary rocks of the KD with which it can possibly be correlated. Metamorphic zircons from a leucosome sample in the southern metagreywacke indicate that it was metamorphosed at ca. 1802 Ma, a typical age for the thermal peak in the KD (Machado et al., 1999). A T_{CR} Nd model age of ca. 2.5 Ga and ε_{Nd} of approximately –1 at 1850 Ma, in comparison, indicate that the paragneiss to the north likely sampled Paleoproterozoic and Neoarchean crust (detrital zircon $^{207}Pb/^{206}Pb$ ages of 2258, 2571 and 2696 Ma were determined in this study).

In summary, Sm-Nd isotope and U-Pb age data suggest that orthogneiss at Pearson Lake might represent a westerly extension of the Mesoarchean Assean Lake crustal complex. At Pearson Lake, Mesoarchean orthogneiss is interleaved with Paleoproterozoic- to Neoarchean-derived paragneiss in the north, and in fault contact with predominantly Paleoproterozoic-derived greywacke-migmatite (probably Burntwood Group) to the south.

Mel zone

The Mel zone was previously shown on compilation maps as part of the KD (e.g., Manitoba Energy and Mines, 1995). However, magnetic trends extend northwest from the TNB at Mystery Lake and exploration drilling by Inco Technical Services Limited has encountered high-grade paragneiss similar to the Ospwagan Group (Fig. GS-14-4). A collaborative program of relogging, geochemistry and Sm-Nd isotope work was undertaken to resolve the geology of this complex area. This paper presents a summary of new petrographic and Nd isotopic results, which suggest that the Mel zone between Mystery Lake and Hunter Lake is part of the northwestern extension of the TNB.

The following lithological units from the TNB are based on a summary review of the Inco drillhole records and were tentatively identified during relogging:

1) Archean basement gneiss
2) lower part of the Ospwagan Group (Manasan Formation M1 quartzite to Pipe Formation P2 pelite and P3 silicate iron formation)
3) greywacke-mudstone–derived gneiss (garnet-biotite gneiss with granitoid leucosome belonging to, or similar to, the Burntwood Group)
4) amphibolite
5) pegmatite and granite veins and sheets, considered to be Proterozoic

The Ospwagan Group is very coarsely recrystallized with garnet porphyroblasts and quartz-sillimanite knots (faserkiesel) reaching 60 mm in length. True thicknesses of Ospwagan Group encountered in the various sections range from 35 to 100 m. Basal quartzite lies — where recognized or preserved — adjacent to basement-type gneiss, which is unusually garnetiferous (probably due to paleoweathering). This suggests that, as in the main TNB, the Ospwagan Group lies unconformably on the basement gneiss. However, unlike the main TNB, the Mel zone features Burntwood-type greywacke migmatite in sharp contact with the Pipe Formation, and the upper part of the Ospwagan Group seems to be absent. True thickness of the Burntwood Group is less than 200 m. Greywacke gneiss, petrographically similar to the Burntwood Group, and amphibolite are the main units encountered in the northwesternmost drillhole.

Neodymium model ages provide a clear distinction between the Archean basement gneiss (T_{CR} = 3.2–3.5 Ga), Ospwagan Group (T_{CR} = 2.8–3.0 Ga), Burntwood Group gneiss (T_{CR} = 2.3–2.4 Ga) and petrographically similar greywacke gneiss derived from older crustal material (T_{CR} approx. 3.2 Ga). The model ages and suggested stratigraphic positions of the analyzed samples are shown in Table GS-14-1.

The oldest Nd model ages of basement gneiss (T_{CR} = 3.4–3.5 Ga) occur in the core of a large oval structure (bottom of DDH 102519, top of DDH 102520; Fig. GS-14-4), whereas banded orthogneiss and paragneiss surrounding the structure (DDH 102523 and top of DDH 102524) yielded T_{CR} Nd model ages of ca. 3.2 Ga. The data indicate a heterogeneous TNB basement with significant Mesoarchean (>3.0 Ga) components in orthogneiss and paragneiss (metagreywacke) along the outer margin of the Superior Boundary Zone.

The Ospwagan Group detritus was eroded from crust with an average time of residence that ranges from 2.8 to 3.0 Ga, consistent with a provenance containing a larger contribution from juvenile Neoarchean rocks than the TNB

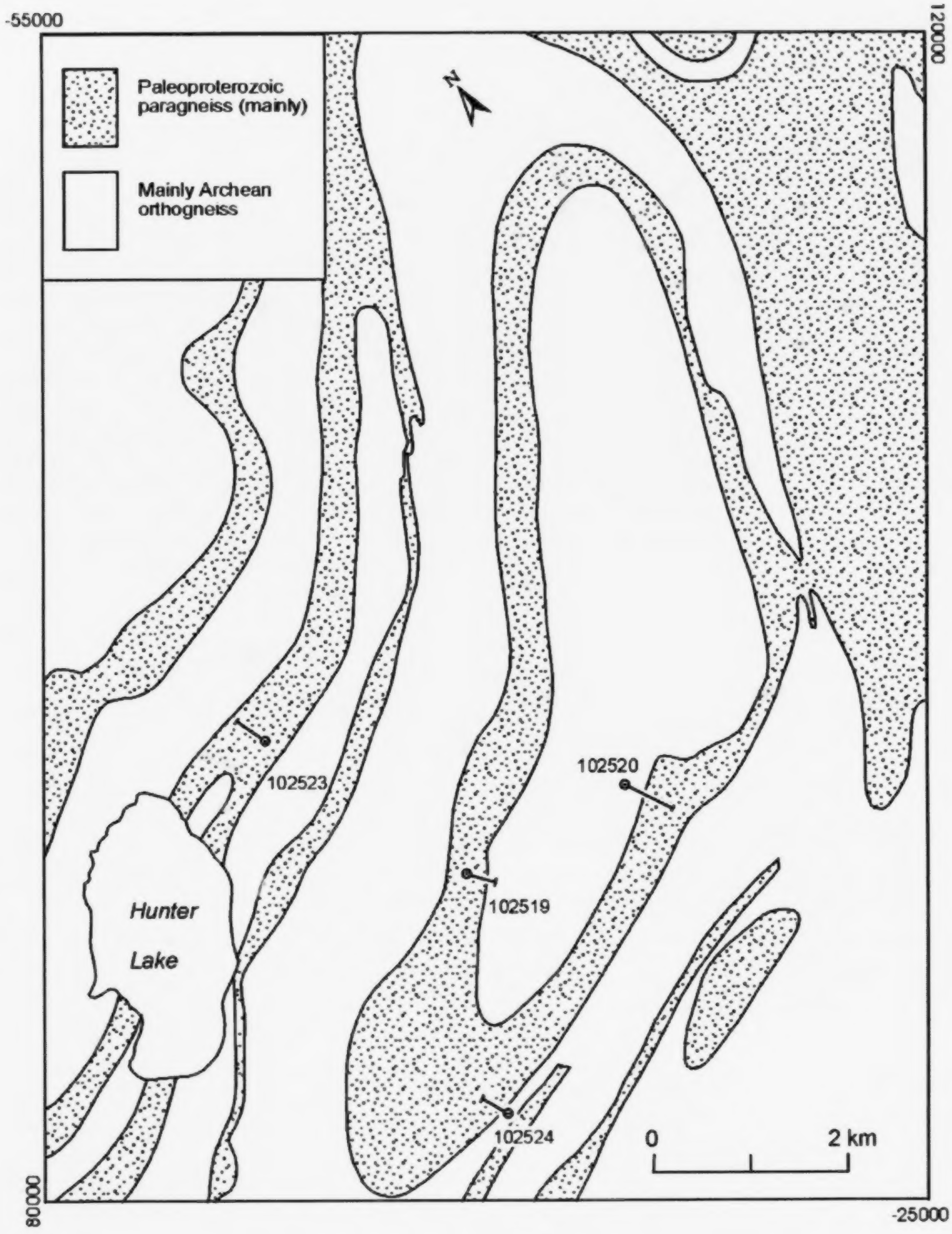

-55000
120000
Paleoproterozoic paragneiss (mainly)
Mainly Archean orthogneiss
N
102523
102520
102519
102524
Hunter
Lake
0
2 km
80000
-25000

Figure GS-14-4: Simplified geological map of the Hunter Lake area (Mel zone), derived from geophysical data (courtesy of Inco Technical Services Limited), showing location of relogged and sampled diamond-drill holes. Inco Thompson grid is shown at the map corners in feet.

Table GS-14-1: Summary of Mel zone drill core stratigraphic interpretation and Nd model ages (T_{CR}).

From (m)	To (m)	Unit / lithology	T_{CR} (Ga)
DDH 102519, 11 km northwest of Mystery Lake:			
33.2	33.8	Burntwood Gp: garnet-biotite greywacke-gneiss	2.3
129.8	130.6	Pipe Fm. (P2): biotite gneiss, mica schist	2.9
205.9	206.8	Basement: Laminated to banded gneiss	3.5
DDH 102520, 10 km northwest of Mystery Lake:			
153.0	154.5	Basement: banded quartzofeldspathic ±garnet gneiss	3.4
389.4	390.2	Manasan Fm. (?M1): garnet-biotite gneiss, biotite quartzite	3.0
404.8	405.1	Manasan Fm. (M2): coarse-grained sillimanite-garnet-biotite gneiss	2.8
536.1	536.7	Burntwood Gp: garnet-biotite metagreywacke-migmatite	2.4
DDH 102523, 2 km northeast of Hunter Lake:			
93.0	536.0	garnet-biotite±sillimanite±cordierite gneiss (greywacke derived)	3.2
DDH 102524, 10 km northwest of Mystery Lake:			
129.2	129.8	Basement: quartzofeldspathic gneiss ±garnet	3.2
389.8	390.5	Thompson Fm. (T3): biotite gneiss	2.9

n.d., not detected

basement. Such rocks are common in the interior part of the Superior Province, which may have been the dominant sediment source. The significantly younger Nd model ages (T_{CR} = 2.3–2.4 Ga) of the Burntwood Group indicate a largely juvenile, Paleoproterozoic detrital component, exotic to the TNB.

A preliminary structural interpretation of the Mel zone is that the Burntwood Group may have been thrust over the TNB with the footwall detachment in the lower part of member P3 of the Pipe Formation. This would suggest that the oval band of paragneiss in Figure GS-14-4 is a recumbent syncline that was developed from an early thrust stack and refolded into a dome (Fig. GS-14-5). If the syncline closes in the southeast, the Burntwood Group and the more ancient orthogneiss are rooted west and north of the TNB, consistent with the regional geology.

Setting Lake area

Samarium-neodymium geochemistry was done under CAMIRO Project 97E-02 (unpublished) at the University of Saskatchewan on several samples collected during regional structural mapping in the Setting Lake area (Zwanzig, 1998). Burntwood Group and Grass River Group paragneiss and dikes, and a quartz-syenite pluton intruding the Grass River Group, all yielded Paleoproterozoic Nd model ages (T_{CR} = 2.2–2.4 Ga) similar to the Burntwood Group in the Mel zone and south of Pearson Lake (Table GS-14-2). The data show that such Nd model ages are regionally typical of the KD paragneiss and intrusions.

New U-Pb zircon crystallization ages, determined at Geotop (Université du Québec à Montréal) by A. Potrel and N. Machado are ca. 1.835 Ga and ca. 1.82 Ga for the mildly alkaline quartz syenite and the granite intruding the quartz syenite, respectively (Table GS-14-2). The ε_{Nd} at the time of crystallization is variably negative and indicates a small to moderate amount of contamination by older rocks, presumably Archean basement gneiss. Archean model ages (T_{CR} = 2.7–2.9 Ga) of the highly foliated K-feldspar–phyric granite and granodiorite gneiss show that these intrusions are moderately to highly contaminated; some may represent remobilized basement gneiss. The data suggest that, similar to the Mel zone, the Kisseynew paragneiss was probably thrust over the Superior Craton margin early during the Hudsonian Orogeny.

Soab Lake–Birchtree Mine area

Relogging of proprietary drill core from Inco Ltd. properties along the west side of the central part of the TNB indicates a good potential for structural slices of juvenile Proterozoic rocks belonging to the KD to occur within the TNB. Conversely, Ospwagan Group and ultramafic rocks associated with nickel deposits elsewhere may be intercalated with juvenile gneiss at the eastern margin of the KD. Sampling from four drill cores for petrographic, geochemical and geochronological analysis has been carried out and sample analysis is in progress. The samples were taken from units of uncertain origin, as well as from recognizable Ospwagan Group metasedimentary rocks. Ten new samples are expected to augment the Nd-Sm database for the TNB and its extensions, and to help solve local problems in structural and exploration geology.

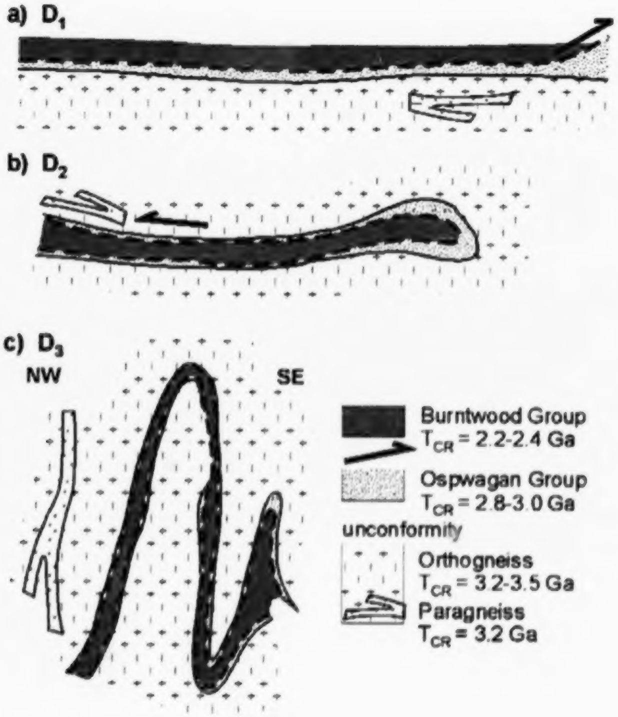


Figure GS-14-5: Possible structural interpretations of the Mel zone in three major phases of deformation. The D_1 thrust fault is inferred from the abrupt change in Sm/Nd isotope ratio between the Ospwagan and Burntwood groups.

Table GS-14-2: Summary of Nd model ages (T_{CR}) and U-Pb zircon ages for the Setting Lake area.

Sample	Location	Unit / lithology / U-Pb zircon age	T_{CR} (Ga)
12-97-7-2B	Setting Lake	Grass River Gp: meta-arenite	2.2
12-98-546-1	Fish Lake	Burntwood Gp: metagreywacke	2.4
12-97-122-21	Setting Lake	Intermediate dike	2.4
12-97-14-3	Setting Lake	Tonalite dike	2.4
12-97-258-1	Setting Lake	Granite (U-Pb zircon age = 1.82 Ga; $\varepsilon_{Nd,1.82\ Ga} = -7.4$)	2.7
12-97-34-3A	Setting Lake	Quartz syenite (U-Pb zircon age = 1.835 Ga; $\varepsilon_{Nd,1.84\ Ga} = -2.3$)	2.4
12-97-99-1	Setting Lake	Granodiorite gneiss	2.9
12-98-624-1	Setting Lake	Porphyroclastic granite	2.7
12-99-915-1	Fish Lake	Porphyroclastic granite	2.9

Rock Lake area

Three recent drill cores of Hudson Bay Exploration and Development Co. Ltd. were re-examined from an area southeast of Rock Lake and extending toward Pearson Lake. Systematic sampling was carried out on the cores for petrographic analysis, and five samples are in preparation for Sm-Nd isotope and detailed geochemical analyses. The resulting data could help delineate the various narrow lithotectonic domains in this critical part of the Superior Boundary Zone.

Assean Lake

Drill core from two holes of Strider Resources Ltd. on the northeast part of Assean Lake was re-examined and sampled for Sm-Nd, geochemical and petrographic work. The cores are mylonitic and units, although poorly preserved, may include clastic and possible cherty to ferruginous metasedimentary members, as well as amphibolite of possible volcanic origin. A comparison of the expected data with surface data from the Assean Lake crustal complex (Böhm et al., 2000, 2002) may place mineralized zones into their regional tectonic context.

Leftrook–Harding lakes area

Although water levels were high and some contacts must be assumed to be faults, the stratigraphic succession identified by Corkery and Lenton (1980) as typical of this part of the north flank of the KD was confirmed during remapping of the shorelines. The succession forms part of the Burntwood and Sickle groups, and locally contains intervening amphibolite (Table GS-14-3).

The regionally widespread greywacke-derived gneiss and migmatite, interpreted as belonging to the Burntwood Group, is exposed for distances of 2 to 5 km in bays, channels and islands, where a set of representative samples was collected.

In several locations, a narrow amphibolite unit occurs at or near the inferred contact between the Burntwood Group and the overlying Sickle Group. The amphibolite is predominantly intrusive into the basal unit of the Sickle Group and the top of the Burntwood Group. However, a 5 to 10 m unit of banded mafic tectonite was probably derived from pillow basalt, but no contacts are exposed to determine its field relationship.

The Sickle Group is generally magnetite bearing and has four distinctive units (undefined formations), recognized mainly by mineral contents of the gneiss (Table GS-14-3). The basal unit (protoquartzite) on Leftrook Lake is 200 to 400 m thick and grades into meta-arenite. This generally grades upward into a unit of medium grey paragneiss. Higher in the section on Leftrook Lake is hornblende-bearing paragneiss that is a minimum of 600 m thick. A quartz-rich, hornblende-bearing unit on Harding Lake grades into an upper unit of meta-arkose that is a minimum of 1000 m thick.

A key observation is that all units compare well to 'stratigraphic' units in the high-grade parts of the Sickle Group further northwest along the north flank of the KD, where they occur within an area of 5000 km^2. Leftrook Lake is an additional 100 km to the east and provides an important link with the paragneiss units in the KD along the Superior Craton boundary. Neodymium model ages and detrital zircon ages of these rocks, and crystallization ages of felsic plutons that cut them, will provide critical tests of the regional tectonostratigraphic correlation.

APPLICATION TO MINERAL EXPLORATION

Distinguishing the relatively juvenile paragneiss of the KD from the Ospwagan Group platform-rift succession and from more ancient paragneiss along the northwestern margin of the Superior Boundary Zone is a key requirement for structural mapping, tectonic modelling, metallogeny and mineral exploration. A recent geological compilation, based primarily on proprietary drill core information (Thompson Nickel Belt Geology Working Group, 2001), has shown that all presently known nickel deposits are hosted in the Ospwagan Group at the site of ultramafic intrusions. Tracing these

Table GS-14-3: Unit description, Leftrook–Harding lakes area.

Lithology	Field description and origin	Petrology
Sickle Group:		
Arkosic gneiss	Grey to buff meta-arkose, ranging from coarse grained to finer grained its upper part	3–50 mm quartz-sillimanite knots (faserkiesel), most abundant high in the unit
Meta-arenite	Greenish grey and pink weathering paragneiss, massive to thinly laminated; locally pebbly or crossbedded on Harding Lake and with rare layers of fine-grained pink felsic gneiss and hornblende-rich gneiss (possibly tuffaceous)	Magnetite and variable amounts of hornblende (<15%) and biotite; local epidote in pebbly layers
Meta-arenite	Uniform, medium grey paragneiss or migmatite interpreted to be derived from lithic arenite	Biotite (<10%) and magnetite (locally 1–2%) as only mafic minerals
Protoquartzite	Biotite-rich laminations with local concentrations of magnetite, interpreted as bedding-plane partings with placer minerals in crossbedding	Quartz rich (50–70%), magnetite-bearing, 3–10% biotite, ~1% garnet (<8 mm, rarely <30 mm), local faserkiesel (<20 mm)
Unnamed amphibolite:		
Gabbro	Concordant bodies; mafic sills, possible dikes	Fine- to medium-grained gabbro, coarse-grained melagabbro and anorthositic gabbro
Mafic tectonite	Possible fault slices derived from pillowed basalt	5–20 mm thick layers rich in hornblende±garnet (sheared selvages); layers, <15 cm thick, rich in diopside (highly metamorphosed epidosite alteration domains)
Burntwood Group:		
Greywacke gneiss and migmatite	Generally dark grey paragneiss, reddish brown cast in graphitic layers; migmatitic leucosome ± garnet ± cordierite porphyroblasts (<20 mm); probably derived from turbidite	Garnet (10–15 %), generally 2 mm, <5 mm in pelitic layers; <5 mm faserkiesel

units at the highest grade of metamorphism (amphibolite to granulite facies) and under a thick cover of Pleistocene clay relies on geophysical and drill core interpretation. However, these exploration techniques present difficulties when attempting to distinguish such units as the sillimanite-garnet-biotite gneiss and migmatite that may be derived from pelite in the Ospwagan Group, the barren Burntwood Group or similar-looking Mesoarchean paragneiss. In addition, the Mesoarchean paragneiss forms part of the Assean Lake crustal complex where gold-bearing zones are under exploration. Unravelling the complex geology at Assean Lake could help to trace these zones further.

The three different tectonic assemblages at the Superior Boundary Zone appear to be structurally interleaved at their margins. Neither the full regional extent nor the structural complexities of these assemblages is presently known. Our Sm-Nd isotope methods, in conjunction with U-Pb dating, applied to the various units provide a clear distinction between the tectonic assemblages. The Sm-Nd isotope work is considerably less expensive than U-Pb zircon dating that has so far provided only very limited data on the age of deposition of the Ospwagan Group (Bleeker, 2001). Furthermore, Nd model ages can be obtained from relatively small samples (i.e., drill core). The preliminary results reported here suggest that this will become a powerful tool for regional metallogeny and local exploration.

ACKNOWLEDGMENTS

The authors thank Inco Limited and Nuinsco Resources Limited for access to their drill core and Inco Technical Services Ltd. staff, particularly Mars Napoli and Monica Proudfoot, for their generous assistance. Hudson Bay Exploration and Development Co. Ltd. and Strider Resources Ltd. provided further drill core and drill logs, and the time and interest of Jim Pickell and Dan Ziehlke are appreciated. The authors also thank Curtis Chmilar, Laura Raynor and Stacey Hagen (University of Alberta) for assistance in the labs and Patrick Norman (University of Manitoba) for his assistance in the field. They are grateful to Bill Yetman of the Nelson House Trust Office (Nisichawayasihk Cree Nation) for helping to obtain council approval for the work at Leftrook Lake.

REFERENCES

Bleeker, W. 1990: New structural-metamorphic constraints on Early Proterozoic oblique collision along the Thompson Nickel Belt, Manitoba, Canada; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 57–73.

Bleeker, W. 2001: New SHRIMP U-Pb ages for the Ospwagan Group: implications for the SE margin of the Trans-Hudson Orogen; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, St. John's, NF, May 27–30, 2001, Abstracts, v. 26, p. 15.

Bleeker, W. and Macek, J.J. 1988: Thompson Nickel Belt Project – Pipe pit mine (part of 63-O/8NE); *in* Report of Field Activities 1988, Manitoba Energy and Mines, Minerals Division, p. 111–115.

Böhm, Ch.O. 1997: GS-6 Geology of the Assean Lake area (parts of NTS 64A 1,2,3,4); *in* Report of Activities 1997, Manitoba Energy and Mines, Geological Services, p. 47–49.

Böhm, Ch.O., Heaman, L.M., Creaser, R.A. and Corkery, M.T. 2000: Discovery of pre-3.5 Ga exotic crust at the northwestern Superior Province margin, Manitoba; Geology, v. 28, no. 1, p. 75–78.

Böhm, Ch.O., Heaman, L.M., Creaser, R.A., Corkery, M.T. and Stern, R.A. 2002: Tectonic assembly of the Trans-Hudson–Superior boundary zone in northern Manitoba: from Paleoarchean crustal remnants to Paleoproterozoic collision; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Saskatoon, Abstracts, v. 27, p. 11.

Corkery, M.T. and Lenton, P.G. 1990: Geology of the Lower Churchill River region; Manitoba Energy and Mines, Geological Report GR85-1, 28 p. and 9 maps at 1:100 000 scale..

DePaolo, D.J. 1981: Neodymium isotopes in the Colorado Front range and crust-mantle evolution in the Proterozoic; Nature, v. 291, p. 193–196.

DePaolo, D.J. 1988: Neodymium Isotope Geochemistry: An Introduction; Springer Verlag, Berlin, 187 p.

Goldstein, S.L., O'Nions, R.K. and Hamilton, P.J. 1984: A Sm-Nd study of atmospheric dust and particulates from major river systems; Earth and Planetary Science Letters, v. 70, p. 221–236.

Machado, N.D., Zwanzig, H.V. and Parent, M. 1999: U-Pb ages of plutonism, sedimentation, and metamorphism of the Paleoproterozoic Kisseynew metasedimentary belt, Trans-Hudson Orogen (Manitoba, Canada); Canadian Journal of Earth Sciences, v. 36, no. 11, p. 1829.

Manitoba Energy and Mines 1995: Bedrock Geology Compilation Map Series, Sipiwesk Lake, NTS 63P, 1:250 000.

Thompson Nickel Belt Geology Working Group 2001: Thompson Nickel Belt geology; Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Maps 2001FS-1 to -5 (1:100 000 scale), 2001HB-1 to -2 (1:100 000 scale), 2001FN-1 to -4 (1:50 000 scale) and 2001I-1 to -4 (1:50 000 scale).

Zwanzig, H.V. 1998: Structural mapping of the Setting Lake area (parts of NTS 63O/1 and 2, and 63J/15); *in* Report of Activities 1998, Manitoba Energy and Mines, Geological Services, p. 40–45.

Zwanzig, H.V., Böhm, Ch.O. and Etcheverry, J. 2001: Superior Boundary Zone–Reindeer Zone Transition in the Pearson Lake–Odei River–Mystery Lake Region (parts of NTS 63P and 64O); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 51–56.

GS-15 THOMPSON NICKEL BELT PROJECT: PROGRESS REPORT (PARTS OF NTS 63J, 63O AND 63P), MANITOBA

by J.J. Macek, C.R. McGregor and C.G. Couëslan[1]

Macek, J.J., McGregor, C.R. and Couëslan, C.G. 2002: Thompson Nickel Belt Project: progress report (parts of NTS 63J, 63O and 63P), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 115-116.

SUMMARY

This past winter, a new topographic map was 80% completed for the exposed part of the Thompson Nickel Belt (TNB), using new orthophoto tiles. Upon completion, the map will serve as a base for the final geological compilation map of the TNB.

During the summer of 2002, the four-year program of re-examining Bucko diamond-drill core was completed. All retrieved geological information will be incorporated into the final TNB compilation map.

For the first time, the Thompson Formation in the South pit of the Thompson mine was sampled for a detailed mineralogical and petrological study. These new data will be compared with those already available from the Manasan quarry and the 1C pit of the Thompson mine.

INTRODUCTION

The purpose of all recent geological work (collecting, organizing and processing data, filling geological gaps, preparing a base map, etc.) is the preparation of a final TNB geological compilation map and accompanying detailed report. Much progress has been made toward this end in the office during the winter of 2001–2002 and in the field during the summer of 2002.

OFFICE ACTIVITY

During the winter of 2001–2002, C.R. McGregor and J.J. Macek transferred from orthophoto tiles all infrastructure features (e.g., paved roads, winter and logging roads, bush trails, railway lines and grades, quarries and gravel pits, cut lines, all visible outcrops) onto a new topographic base map that covers the exposed part of the TNB between Moak Lake (northeast of Thompson) and Gormley Lake (southwest of Wabowden). When completed, this new detailed topographic map will serve as a base for all currently available geological information. Some information is already published on preliminary compilation maps of the TNB (Thompson Nickel Belt Geology Working Group, 2000f, g, h) but will be geographically corrected. All new unpublished geological information will be added (Macek et al., 2001). The final product will be a new, GIS-compatible, geological compilation map series of the TNB.

FIELD ACTIVITY

During the 15-week summer field season of 2002, two tasks were accomplished:

- Re-examination of the diamond-drill core stored at Wabowden was completed.
- Geological data and samples were collected from the South pit of the Thompson mine.

Re-examination of the diamond-drill core

The last portion of the diamond-drill core stored at Wabowden has been re-examined. This concludes the four-year program of retrieving geological data begun in 1999 (Macek et al., 1999). When this program was initiated, more than 15 000 boxes of diamond-drill core were stored in outside racks and crosspiles at the Falconbridge Limited Bucko exploration site. This core, which originated from numerous exploration targets drilled in the southern portion of the exposed TNB, represents a valuable source of geological information from a terrane heavily covered by glacial deposits.

The core was moved to Wabowden (Macek et al., 1999) and relogged in subsequent years (Macek et al., 2000, 2001, this report). Geological data thus obtained in 2000 are already incorporated into some preliminary compilation maps of the TNB (Thompson Nickel Belt Geology Working Group, 2000f, g, h). The data obtained from 2001 and 2002 relogging will be incorporated in the final TNB geological compilation maps.

During the re-examination process, all geological units were photographically documented and the core was abbreviated. Where possible, generous portions of the core were saved for future geochemical and geochronological investigations. The abbreviated core is stored at the Manitoba Geological Survey (MGS) Drill Core Library in Winnipeg.

---

[1] Geology Department, Brandon University, Brandon, Manitoba R7A 6A9

Falconbridge Limited is gratefully acknowledged for providing access to this core and all derived documentation. Both the documentation and the core will be accessible to the public at the MGS core library, once they are properly organized and arranged for easy viewing.

Data collection from the South pit of the Thompson mine

The Manasan and Thompson formations of the Ospwagan Group are spectacularly exposed on the western shoulder of South pit at the Thompson mine. These outcrops, which are currently the best available exposures of these formations in the TNB, had never been sampled in detail prior to 2002. They offer an excellent opportunity for detailed mineralogical and petrological studies, and to properly document this important information for these formations. Inco Limited is gratefully acknowledged for granting permission to C.G. Couëslan to conduct these investigations as a basis for his B.Sc. Honours thesis. Mineralogy and petrography of the Thompson Formation 'skarns' will be compared with those of equivalent rocks at both the Manasan quarry and the 1C pit of the Thompson mine. The results will be published in next year's *Report of Activities*.

ACKNOWLEDGMENTS

Once again, the authors gratefully acknowledge the generous logistical and personnel support provided by Falconbridge Limited, including free access to proprietary data; without this assistance, a great part of the TNB project would not have been possible.

Inco Limited is gratefully acknowledged for their very generous and continuous support of all investigations conducted in the TNB, including the latest ones conducted in the South pit of the Thompson mine and the Manasan quarry.

The authors also thank summer assistants F.E. McGregor, P.E. Norman, T.L. Parsons, S.M. Romancyshyn, M.R. Trott and S.J. Venton for their valuable assistance and meticulous work, performed reliably under difficult conditions.

REFERENCES

Macek, J.J., Ducharme, E.B., Lettley, C. and McGregor, C.R. 1999: Retrieval of the diamond drillcore from Falconbridge's Bucko exploration site near Wabowden (parts of NTS 63J, 63O and 63P); *in* Report of Activities 1999, Manitoba Energy and Mines, Geological Services, p. 15–17.

Macek, J.J., McGregor, C.R. and Zwanzig, H.V. 2000: Thompson Nickel Belt Project: progress on a new compilation map of the Thompson Nickel Belt (parts of NTS 63F, 63G, 63J, 63O and 63P); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 13–15.

Macek, J.J., McGregor, C.R. and Zwanzig, H.V. 2001: Thompson Nickel Belt Project: progress report; *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 47–50.

Thompson Nickel Belt Geology Working Group 2001f: Geology of the Pakwa Lake area (63J/15); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map 2001FN-2, scale 1:50 000.

Thompson Nickel Belt Geology Working Group 2001g: Geology of the Pistol Lake area (63O/2); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map 2001FN-3, scale 1:50 000.

Thompson Nickel Belt Geology Working Group 2001h: Geology of the Half Lake area (63O/1); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map 2001FN-4, scale 1:50 000.

GS-16 INTERPRETATION OF THOMPSON-TYPE GEOPHYSICAL SIGNATURES (NTS 63B AND 63F) AND THE POSSIBLE CAUSE OF THE CAMPERVILLE GRAVITY LOW (NTS 62N AND 63C), WEST-CENTRAL MANITOBA

by I.T. Hosain and J.D. Bamburak

Hosain, I.T. and Bamburak, J.D. 2002: Interpretation of Thompson-type geophysical signatures (NTS 63B and 63F) and the possible cause of the Camperville gravity low (NTS 62N and 63C), west-central Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 117-130.

SUMMARY

Gravity and magnetic surveys were carried out in the summers of 2000 and 2001 over the southern extension of the Superior Boundary Zone. The purpose of the surveys was to delineate the Thompson Nickel Belt below the Paleozoic cover rocks and to determine the cause of a neighbouring gravity low in the Camperville area.

This project outlines the Thompson Nickel Belt within a gravitational low along The Pas Moraine, where there are short-wavelength, low-amplitude magnetic anomalies. This setting is interpreted as the signature that the Thompson deposits would have if they were situated beneath approximately 200 m of cover rocks.

In the Camperville area, a large, ellipsoidal, 35 mGal gravity low, measuring approximately 120 km by 60 km, is interpreted to be a granitic intrusion with a high concentration of magnetite.

INTRODUCTION

Gravity and magnetic surveys were carried out over the southern extension of the Superior Boundary Zone (SBZ) during the summers of 2000 and 2001 (Fig. GS-16-1). The purpose of the surveys was to delineate the southern extension of the Thompson Nickel Belt (TNB) and to determine the cause of the large gravity low in the Camperville area. One 200 km profile along The Pas Moraine (Provincial Highway 60) and several profiles across the Camperville anomaly were carried out with the assistance of students from the University of Manitoba's Earth Science Department. The survey traverses are shown in Figures GS-16-2 and GS-16-3.

GEOLOGICAL SETTING

The southern extension of the Precambrian SBZ in southwestern Manitoba (Fig. GS-16-1) is buried beneath an increasing thickness of Phanerozoic strata towards the southwestern corner of the province. The SBZ is bounded to the east by the Archean craton of the Superior Province, and to the west by the Trans-Hudson Orogen (see Fig. GS-17-1, this volume). The 2000 and 2001 study areas, shown in Figures GS-16-2 and GS-16-3, are situated within the outcrop belts of Paleozoic (Silurian and Devonian) and Mesozoic (Cretaceous) formations. The Ordovician to Devonian and Cretaceous stratigraphy of the study areas is shown in Figure GS-17-2 (this volume).

The Superior Province is divided into various domains and subdomains (Fig. GS-17-1, this volume). The domain and subdomain boundaries form T-intersections with the SBZ. The Camperville gravity low, a major gravity anomaly adjacent to the SBZ within the Berens River Domain, is also shown in Figure GS-17-1 (this volume) and in Figure GS-16-1.

Pleistocene glacial till and lacustrine sediments overlie the Paleozoic and Mesozoic outcrop belts. The Pas Moraine is a major glacial feature that crosses the SBZ (and the 2001 study area) from northwest to southeast.

GEOPHYSICAL SURVEYS

The general description of the surveys and preliminary interpretation are outlined in the 2000 and 2001 Reports of Activities (Bamburak et al., 2000; Surasky and Minkus, 2000; Surasky et al., 2001). The gravity and magnetic surveys were carried out over an eight-day period in 2000 and an eight-day period in 2001. The instruments used were a Worden gravity meter and an MP-3 proton-precession magnetometer. Station spacing was 1 km. The gravity and magnetic readings were recorded simultaneously at stations off the shoulder of the highways. A base station was visited every 2 hours to correct for drift in the gravity meter and for diurnal corrections for the magnetic survey. Because terrain in the area was relatively flat, terrain corrections were not applied to the gravity data.

BACKGROUND

Aeromagnetic anomalies in the SBZ appear to be produced by the upper level of the buried Precambrian rocks. In

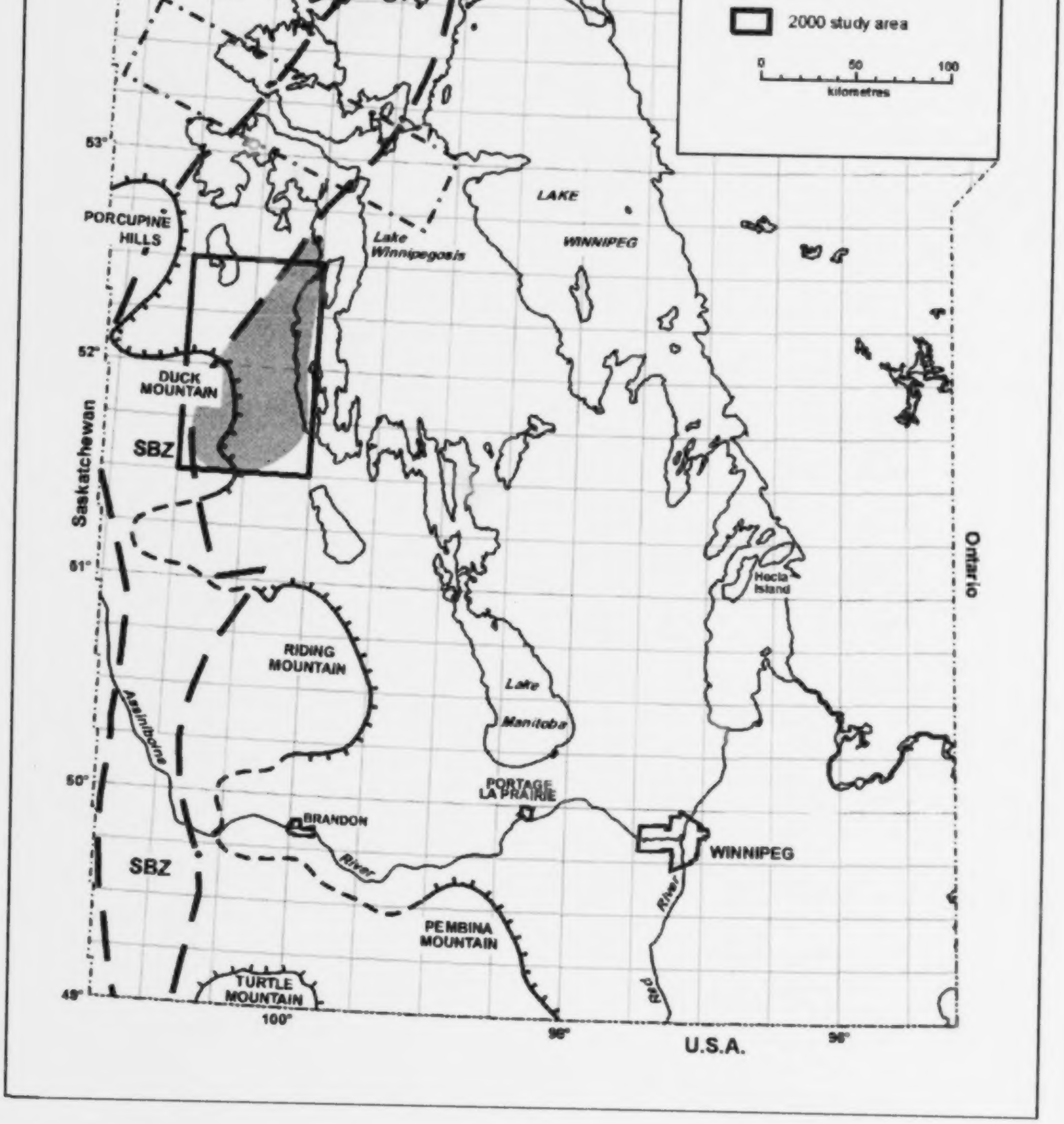
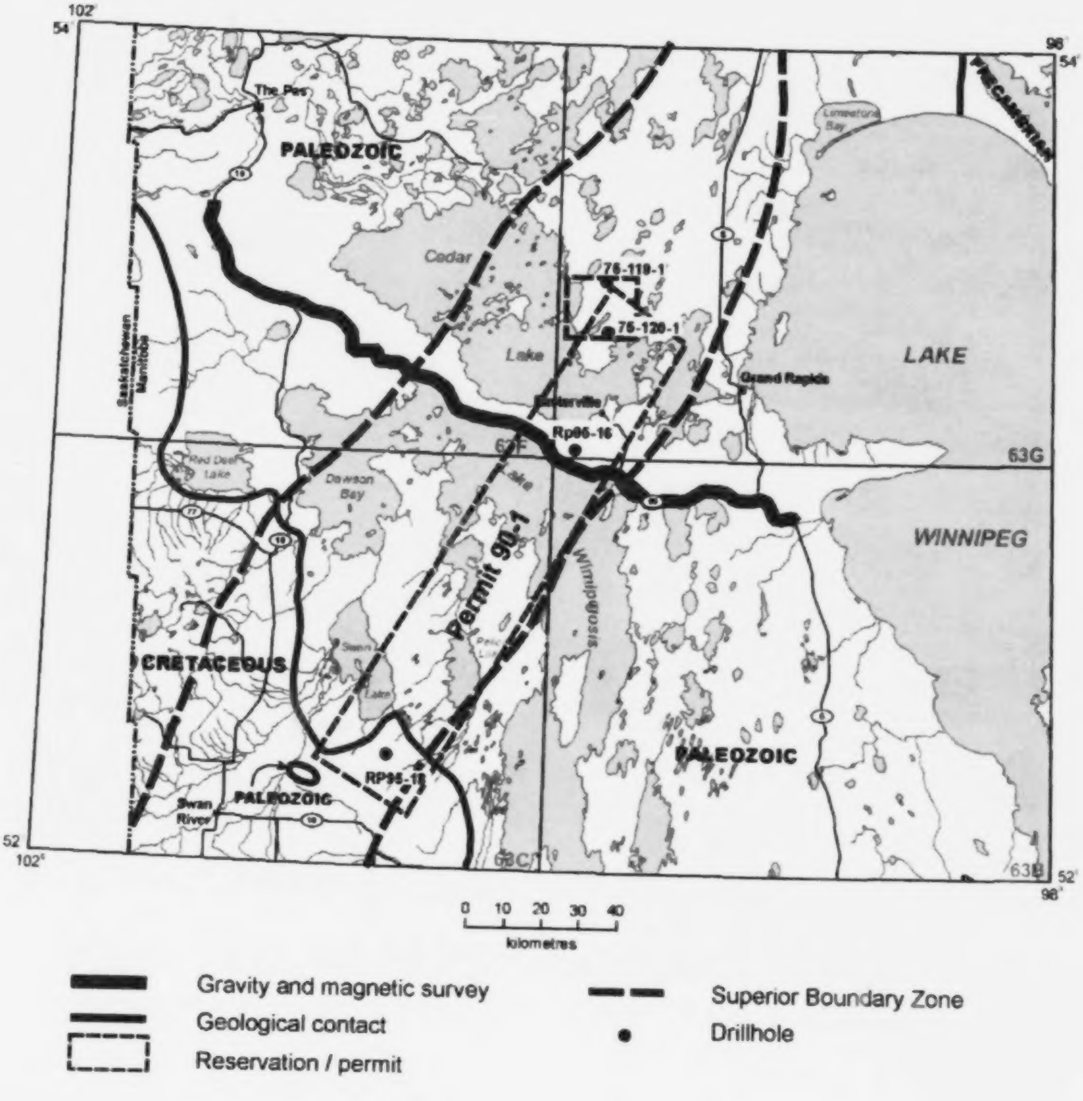

Manitoba Escarpment
Superior Boundary Zone
Camperville gravity low
2001 study area
2000 study area
0
50
100
kilometres
55°
FLIN FLON
54°
SBZ
53°
PORCUPINE HILLS
Lake Winnipegosis
LAKE
WINNIPEG
52°
DUCK MOUNTAIN
SBZ
Saskatchewan
Ontario
51°
Hecla Island
RIDING MOUNTAIN
Lake Manitoba
Assiniboine
50°
PORTAGE LA PRAIRIE
BRANDON
River
WINNIPEG
Red
River
SBZ
PEMBINA MOUNTAIN
TURTLE MOUNTAIN
49°
100°
98°
96°
U.S.A.

Figure GS-16-1: Location of study areas, showing the Manitoba Escarpment, Superior Boundary Zone and Camperville gravity low.



102°
54°
98°
54°
The Pas
PALEOZOIC
Cedar
Lake
76-119-1
76-120-1
LAKE
Grand Rapids
Easterville
Rp95-16
63F
63G
Red Deer Lake
Dawson Bay
WINNIPEG
Permit 90-1
Winnipegosis
Lake
CRETACEOUS
PALEOZOIC
Swan Lake
RP95-18
Swan River
PALEOZOIC
Saskatchewan
Manitoba
PRECAMBRIAN
Limestone Bay
63C
63B
52°
102°
52°
98°
0 10 20 30 40
kilometres
Gravity and magnetic survey
Geological contact
Reservation / permit
Superior Boundary Zone
Drillhole

Figure GS-16-2: Location of traverse along The Pas Moraine.

contrast, the gravity patterns appear to be produced by large-scale density contrasts, which are not related to near-surface Precambrian material. The serpentinized peridotite bodies of the TNB, which occur scattered along the axis of a gravity low, are too small to influence the regionally spaced gravity values of the SBZ. It is believed that a deeper crustal source is the cause of the gravity anomalies (Gibb, 1968). If any gravity anomalies were directly caused by the ultramafic rocks, then one would expect to see a correlation with the magnetic peaks. If anything, the opposite seems to be the case. The positive magnetic peaks have shorter wavelengths, reflecting shallow causative bodies.

North of Thompson, within the Hudson Bay Lowlands, the peridotite bodies were drilled by Kennco Explorations (Canada) Limited along the Weir River gravity low, shown in Figure GS-16-4 (Assessment File 91702, Manitoba Industry, Trade and Mines, Winnipeg). The coincidence of a peridotite and a gravity low corresponds to that found at the Thompson-Moak deposits area.

The Setting Lake gravity low, the Mystery Lake low and the Split Lake low (Fig. GS-16-4) outline a belt of amphibolite-facies rocks (Gibb, 1968). The largest area of granite mapped at the surface within the belt, at Split Lake, underlies the most negative gravity values. Measurements show that the granite has a density of 2.60 g/cm^3. The negative anomaly can be explained if it extends to a depth of 7 km (Gibb, 1968).

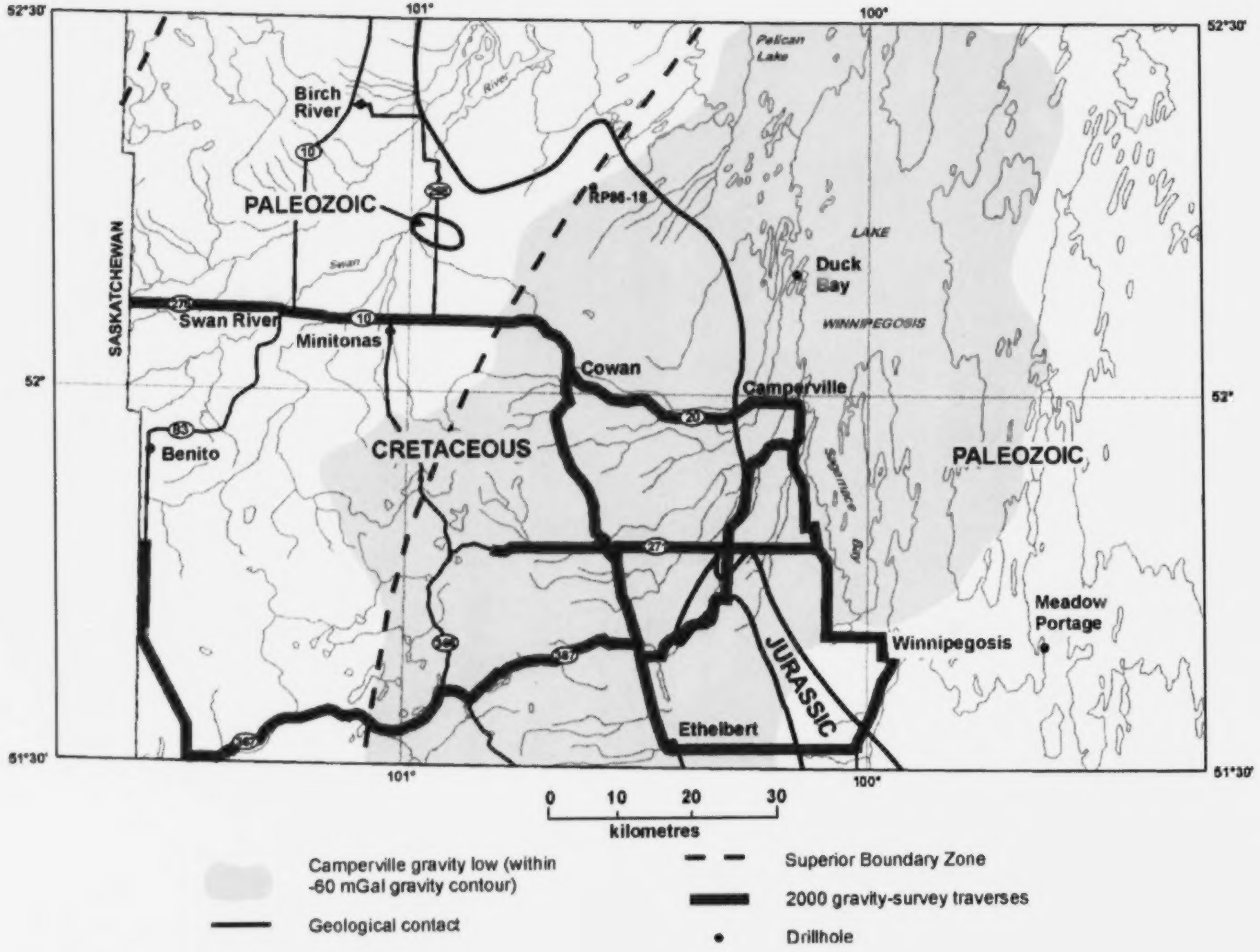

52°30'
101°
100°
52°
51°30'
SASKATCHEWAN
Birch River
PALEOZOIC
Swan
River
RP86-18
Pelican Lake
LAKE
WINNIPEGOSIS
Duck Bay
Swan River
Minitonas
Cowan
Camperville
Benito
CRETACEOUS
Sagemace Bay
PALEOZOIC
Meadow Portage
Winnipegosis
JURASSIC
Ethelbert
10
268
270
20
83
27
366
367
0
10
20
30
kilometres
Camperville gravity low (within -60 mGal gravity contour)
Geological contact
Superior Boundary Zone
2000 gravity-survey traverses
Drillhole

Figure GS-16-3: Location of traverses across the Camperville gravity low.

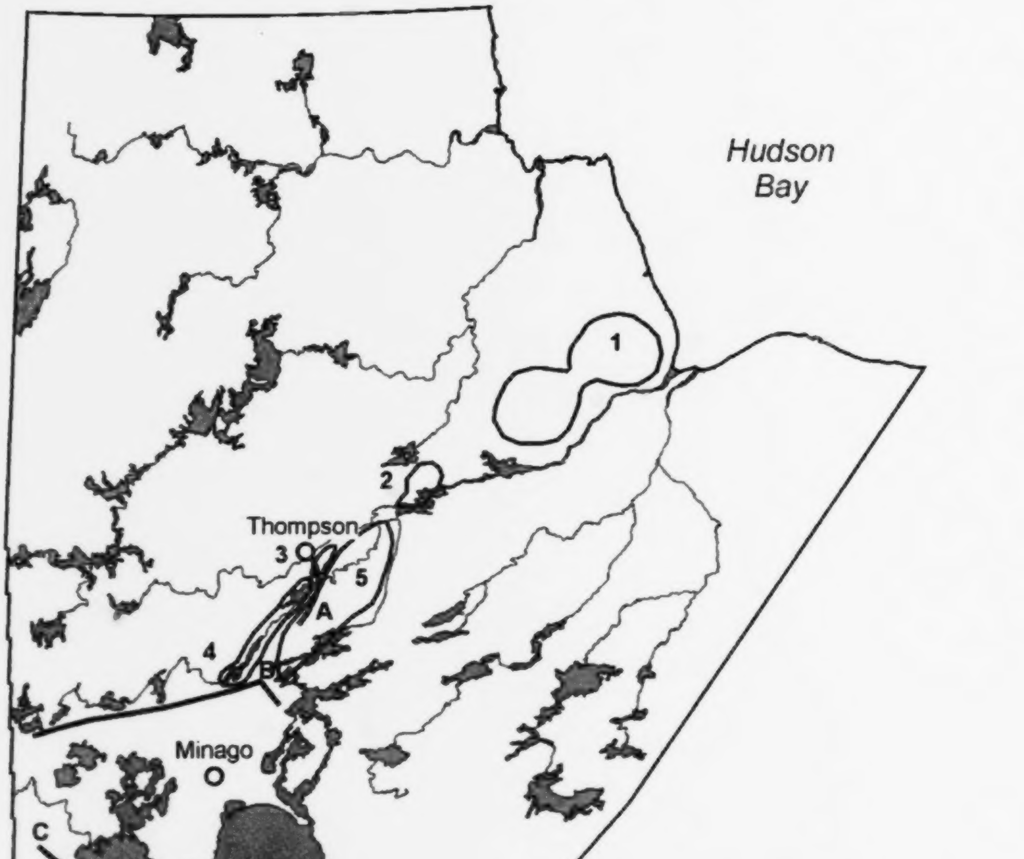

Hudson Bay
1
2
Thompson
3
5
A
4
B
Minago
C
Lake
Winnipeg
Winnipeg
50 0 100
kilometres
Location of Gravity Lows & Highs
Low:
1 Weir Lake
2 Split Lake
3 Mystery Lake
4 Setting Lake
High:
5 Nelson River
Location of Seismic Profiles
A Thompson-Moak
B Provincial Hwy. 391
C Provincial Hwy. 60
O Location of deposit

Figure GS-16-4: Location of seismic profiles relative to gravity lows and highs.

The Nelson River gravity high is related to the Archean granulite-facies rocks of the Pikwitonei Subprovince (Fig. GS-16-4). These rocks range in composition from charnockite to metagabbro (Gibb, 1968). To satisfy these geophysical anomalies, the Pikwitonei granulite would have to extend beneath the TNB with a west-dipping boundary separating the two units (Thomas and Tanczyck, 1994).

Seismic surveys were carried out under the LITHOPROBE Project (Lucas et al., 1996) along three traverses across the TNB (Fig. GS-16-4). The northernmost traverse was in the vicinity of Thompson, the central one along Provincial Highway 391 (along the Flin Flon–Snow Lake greenstone belt) and the southernmost one along Provincial Highway 60 (approximately 200 m of Paleozoic rocks overlie the Precambrian in the southernmost traverse). Interpretation of the data has been carried out by various scientists. For this project, interpretations of the southernmost two profiles are relevant.

PREVIOUS INTERPRETATION

The LITHOPROBE interpretation of the seismic traverse along Provincial Highway 60 is shown in Figures GS-16-5 and GS-16-6 (Lucas et al., 1996). The geology of the SBZ changes along strike to the south. In the vicinity of line 3SB (Provincial Highway 60), it includes a homoclinal, west-dipping, west-facing succession of subgreenschist metamorphic grade sedimentary and volcanic rocks that unconformably overlies Superior Province basement. The succession comprises a thin interval of discontinuous basal conglomerate and sandstone overlain by tholeiitic basalt (Grand Island and Upper tholeiite units) and komatiite. Age determinations indicate that the mafic-ultramafic volcanic package is significantly younger than the Ospwagan Group. Contacts between the various mafic-ultramafic volcanic sections have been interpreted as thrust faults, although the lower tholeiite-komatiite contact may be stratigraphic (Lucas et al., 1996).

The Muddy Bay metasedimentary unit is of uncertain affinity and may correspond to either the Burntwood Group or the Ospwagan Group of the Reindeer Zone and SBZ, respectively. The granite to the west of the Muddy Bay metasedimentary unit is interpreted as part of the Kisseynew Domain. It is succeeded, to the west, by typical Kisseynew Domain units, Burntwood and Missi Group metasedimentary rocks and, near its termination, by units of the Flin Flon Belt (Lucas et al., 1996).

PRESENT INTERPRETATION

The correlation between the exposed Precambrian rocks and their geophysical signature was determined in various areas by Gibb (1968), Roth (1975) and Thomas and Tanczyck (1994); their results were used to derive the present interpretation of the geology below the Paleozoic rocks. Interpretation of the profile along The Pas Moraine was carried out first, as this was closer to the exposed Precambrian than the Camperville area. The profile also crosses Cominco Limited permit areas, where drillhole information is available (drillhole RP95-16, shown in Fig. GS-16-2, GS-16-7; Assessment File 94638, Manitoba Industry, Trade and Mines, Winnipeg). The LITHOPROBE seismic data interpretation of the traverse along The Pas Moraine (line S3B) was also available and used for correlation purposes (Fig. GS-16-5, GS-16-6).

The published specific gravity and magnetic susceptibility of various rocks are shown in Table GS-16-1.

Modelling of the gravity and magnetic data was carried out using the computer programs GRAV2DC for Windows and MAG2DC for Windows (Cooper, 1998, 2000).

THE PAS MORAINE

The gravity and total-field magnetic profiles, together with the interpreted models, are shown in Figures GS-16-7 and GS-16-8. Some preliminary modelling was carried out by Surasky et al. (2001). Their resulting models are compatible with the present, more detailed interpretation.

In constructing the models, the depth of the Precambrian was set at 200 m, based on drillhole information and the *Stratigraphic Map Series* (Bezys and Conley, 1998). The width, dip, density contrast and susceptibility contrast of lithological units were altered until a reasonable match was obtained between the calculated and observed profiles. The gravity profile was much smoother than the magnetic profile, indicating deep-seated causative bodies. The magnetic profile contained short-wavelength, high-frequency anomalies superimposed on long wavelength anomalies, which reflects more surficial causative bodies superimposed on deeper bodies. Because the program can model a maximum of 16 bodies at a time, the short-wavelength anomalies were not modelled. The interpreted dips of the various lithological units were compatible with the dips of the interpreted seismic reflectors. All available information from

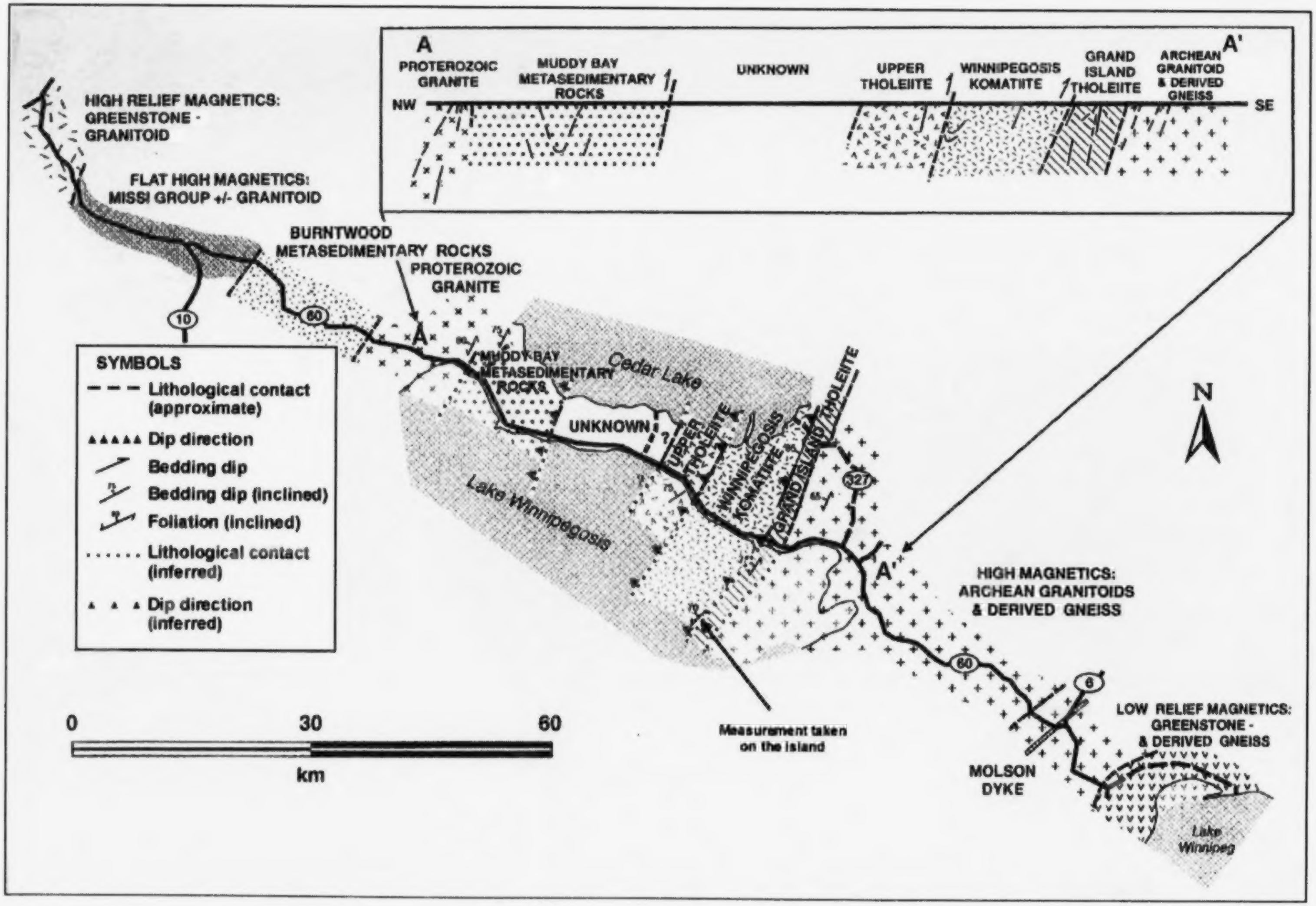

A
PROTEROZOIC GRANITE
MUDDY BAY METASEDIMENTARY ROCKS
UNKNOWN
UPPER THOLEIITE
WINNIPEGOSIS KOMATIITE
GRAND ISLAND THOLEIITE
ARCHEAN GRANITOID & DERIVED GNEISS
A'
NW
SE
HIGH RELIEF MAGNETICS: GREENSTONE - GRANITOID
FLAT HIGH MAGNETICS: MISSI GROUP +/- GRANITOID
BURNTWOOD METASEDIMENTARY ROCKS
PROTEROZOIC GRANITE
A
10
60
MUDDY BAY METASEDIMENTARY ROCKS
Cedar Lake
UNKNOWN
UPPER THOLEIITE
WINNIPEGOSIS KOMATIITE
GRAND ISLAND THOLEIITE
327
Lake Winnipegosis
A'
HIGH MAGNETICS: ARCHEAN GRANITOIDS & DERIVED GNEISS
N
SYMBOLS
Lithological contact (approximate)
Dip direction
Bedding dip
Bedding dip (inclined)
Foliation (inclined)
Lithological contact (inferred)
Dip direction (inferred)
0
30
60
km
Measurement taken on the island
60
6
MOLSON DYKE
LOW RELIEF MAGNETICS: GREENSTONE - & DERIVED GNEISS
Lake Winnipeg

Figure GS-16-5: Map view of lithological units along The Pas Moraine traverse (from Lucas et al., 1996).

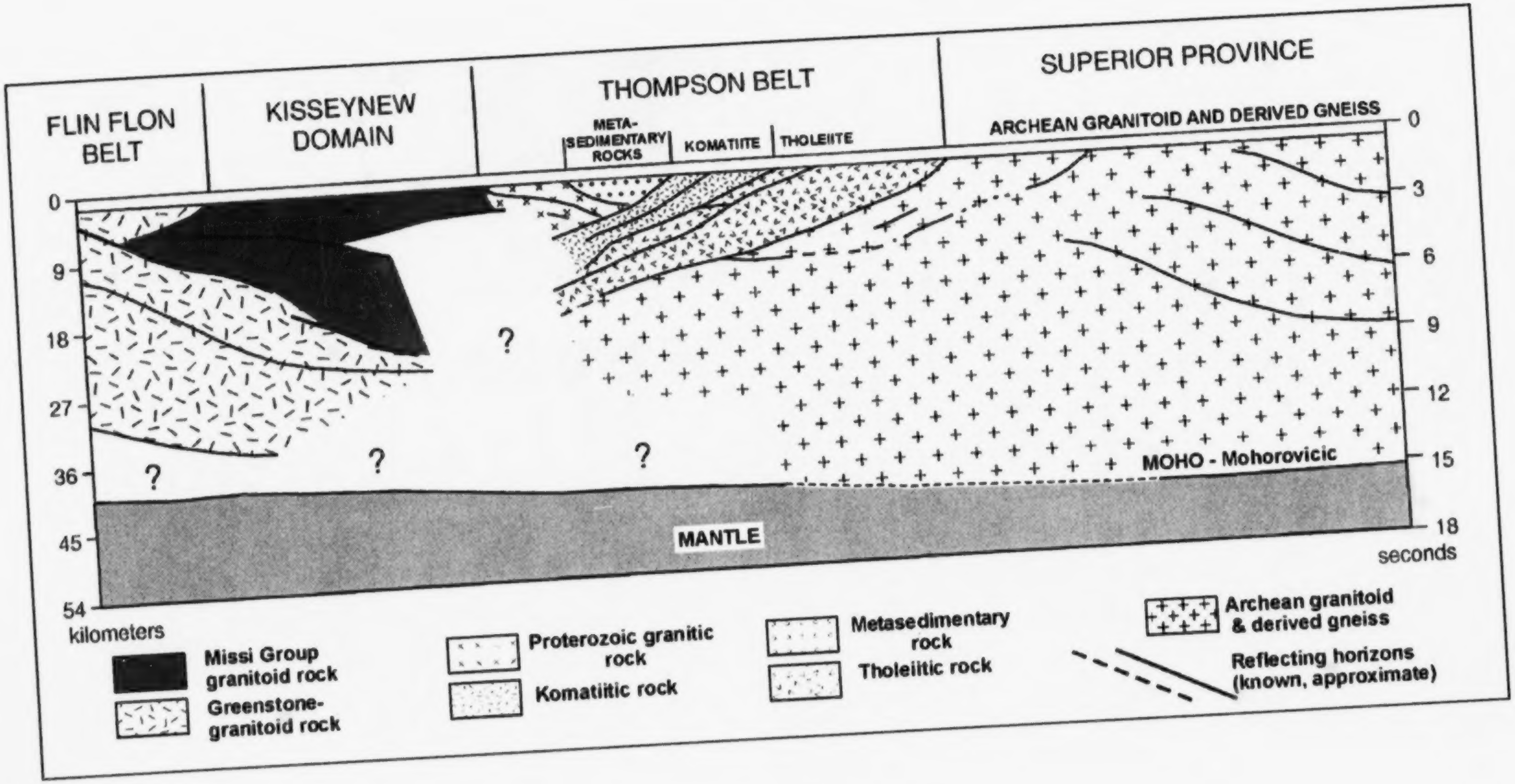

FLIN FLON BELT
KISSEYNEW DOMAIN
THOMPSON BELT
META-SEDIMENTARY ROCKS
KOMATIITE
THOLEIITE
SUPERIOR PROVINCE
ARCHEAN GRANITOID AND DERIVED GNEISS
0
9
18
27
36
45
54
kilometers
0
3
6
9
12
15
18
seconds
?
?
?
?
MOHO - Mohorovicic
MANTLE
Missi Group granitoid rock
Greenstone-granitoid rock
Proterozoic granitic rock
Komatiitic rock
Metasedimentary rock
Tholeiitic rock
Archean granitoid & derived gneiss
Reflecting horizons (known, approximate)

Figure GS-16-6: Seismic model along The Pas Moraine traverse (from Lucas et al., 1996).

Table GS-16-1: Published specific gravity and magnetic susceptibility values (Gibb, 1968; Roth, 1975; Thomas and Tanczyck, 1994).

Rock type	Specific gravity (g/cm^3)	Susceptibility ($\times 10^{-6}$ cgs units)
Limestone	2.55	10
Argillite	2.41	
Serpentinite	2.47–2.60	300
Dunite	2.38–2.51	24–400
Granite	2.64	20
Tonalite	2.67	
Gneiss	2.67–2.70	16–25
Metasedimentary rocks	2.62–2.90	
Granulite	2.73–2.84	160–250
Dolomite	2.8	0–7.5
Dolomitic marble	2.85	
Carbonate rich sedimentary rocks	2.91	0.1–1.0
Basalt	3.04	300–600
Gabbro	2.93–3.07	600
Amphibolite	2.89–3.13	
Peridotite	3.15	1300

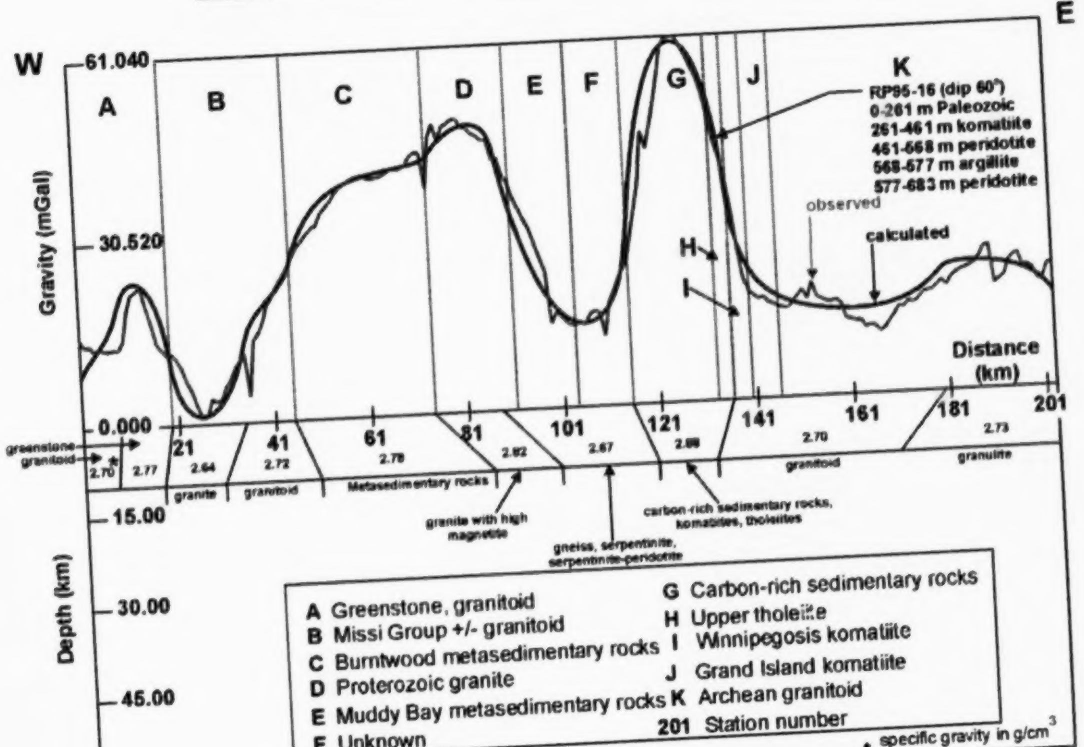


Figure GS-16-7: Gravity profile, with interpreted model, along The Pas Moraine traverse. Upper case letters indicate lithological units interpreted from the seismic survey. Interpreted rock types arrived at using both gravity and magnetic data are shown in small type.

drillholes in the area was utilized. The densities and magnetic susceptibilities are plotted on the models. A background density of 2.67 g/cm^3 was used to determine the densities of the various rock units.

The lithological units interpreted from the seismic survey are indicated by upper case letters on Figures GS-16-7 and GS-16-8. The interpreted rock types arrived at using both the gravity and magnetic data are shown in small type on Figure GS-16-7. There are a few magnetic peaks in the area of the gravity low (between stations 90 and 110).

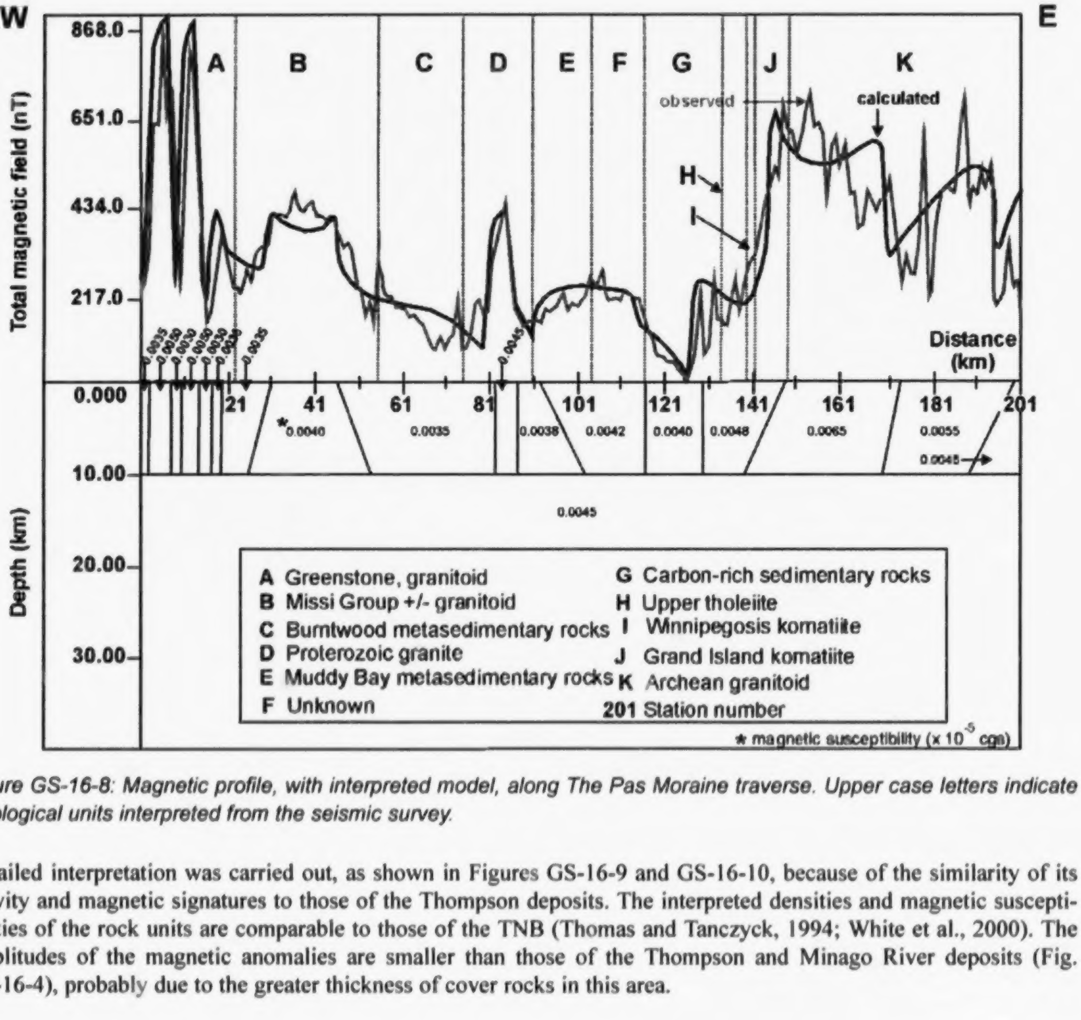


Figure GS-16-8: Magnetic profile, with interpreted model, along The Pas Moraine traverse. Upper case letters indicate lithological units interpreted from the seismic survey.

Detailed interpretation was carried out, as shown in Figures GS-16-9 and GS-16-10, because of the similarity of its gravity and magnetic signatures to those of the Thompson deposits. The interpreted densities and magnetic susceptibilities of the rock units are comparable to those of the TNB (Thomas and Tanczyck, 1994; White et al., 2000). The amplitudes of the magnetic anomalies are smaller than those of the Thompson and Minago River deposits (Fig. GS-16-4), probably due to the greater thickness of cover rocks in this area.

CAMPERVILLE GRAVITY LOW

The gravity and total-field magnetic profiles along Provincial Highways 275, 10 and 20, from Camperville to the Saskatchewan-Manitoba boundary, are shown in Figures GS-16-11 and GS-16-12, together with the interpreted models. This profile was chosen over the other two because it is approximately perpendicular to the strike of the ellipse. Some preliminary modelling was carried out by Surasky and Minkus (2000). Their resulting models are compatible with the present, more detailed interpretation. The modelling was carried out in a manner similar to that of The Pas Moraine traverse, except that the depth to the Precambrian was increased to between 500 and 800 m, going from east to west, in accordance with data on the *Stratigraphic Map Series* (Bezys and Conley, 1998).

There are similarities between the profiles from the Camperville gravity low and those along The Pas Moraine. The observed Camperville profiles are smoother than those on The Pas Moraine, which is to be expected from causative bodies that are more deeply buried. Also, the western end is smoother than the east, again reflecting thicker cover rocks. The major difference between the two profiles is the 35 mGal gravity low in the southern profile. Modelling interpreted the cause of this to be a higher level structure containing low-density material, probably granite (2.64 g/cm^3). These rocks are interpreted to have high magnetite content, producing the high magnetic anomaly. The underlying rock unit has a calculated density of 2.73 g/cm^3, which would put it in the range of Pikwitonei granulite. At station 50, there are coincident gravity and magnetic highs, which modelling interpreted as being due to a sill with a density of 2.92 g/cm^3 and magnetic susceptibility of 1200 x 10^{-5} cgs units; this would put it in the range of a peridotite. Approximately 20 km northeast of this traverse (along strike with Cominco's southernmost drillhole on their permit 90-1), drillhole RP95-18

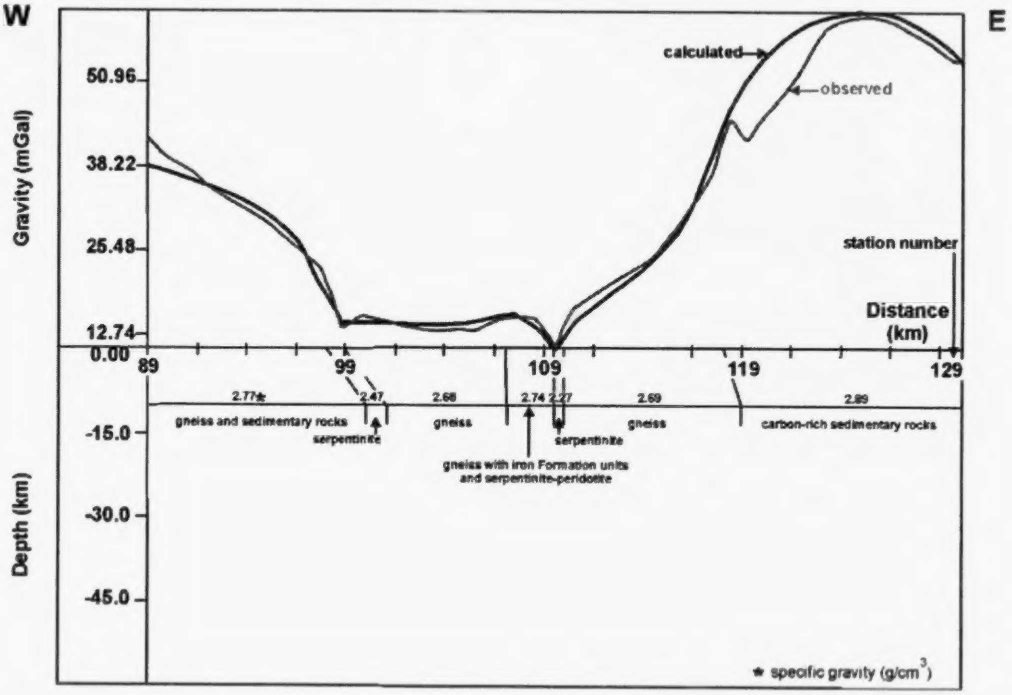


Figure GS-16-9: Detailed gravity profile, with interpreted model, of the area between stations 89 and 129 on The Pas Moraine traverse.

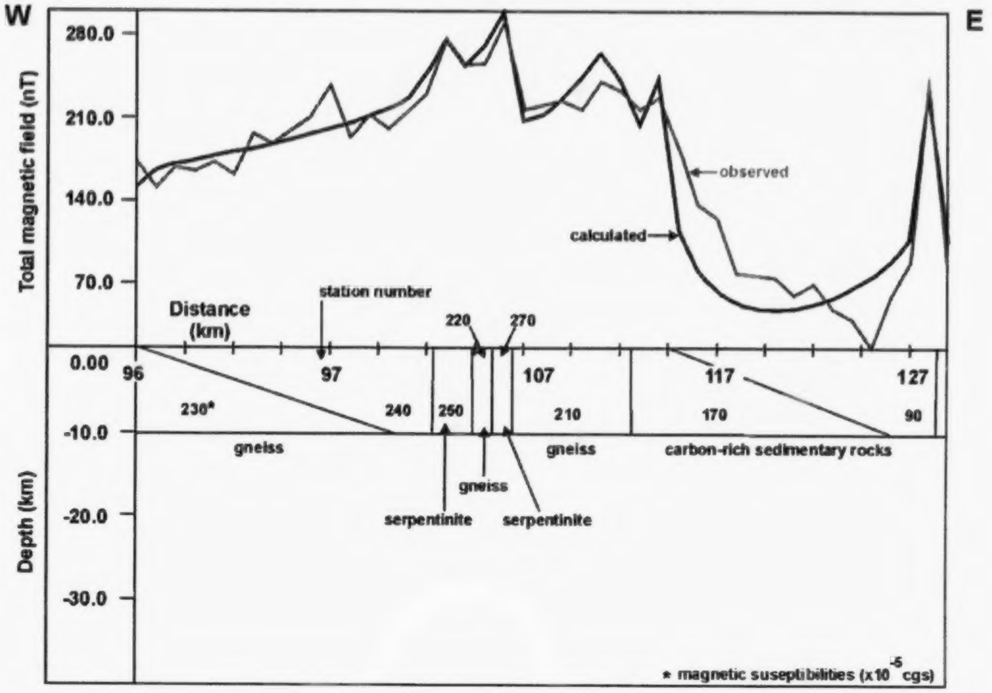


Figure GS-16-10: Detailed magnetic profile, with interpreted model, of the area between stations 96 and 127 on The Pas Moraine traverse.

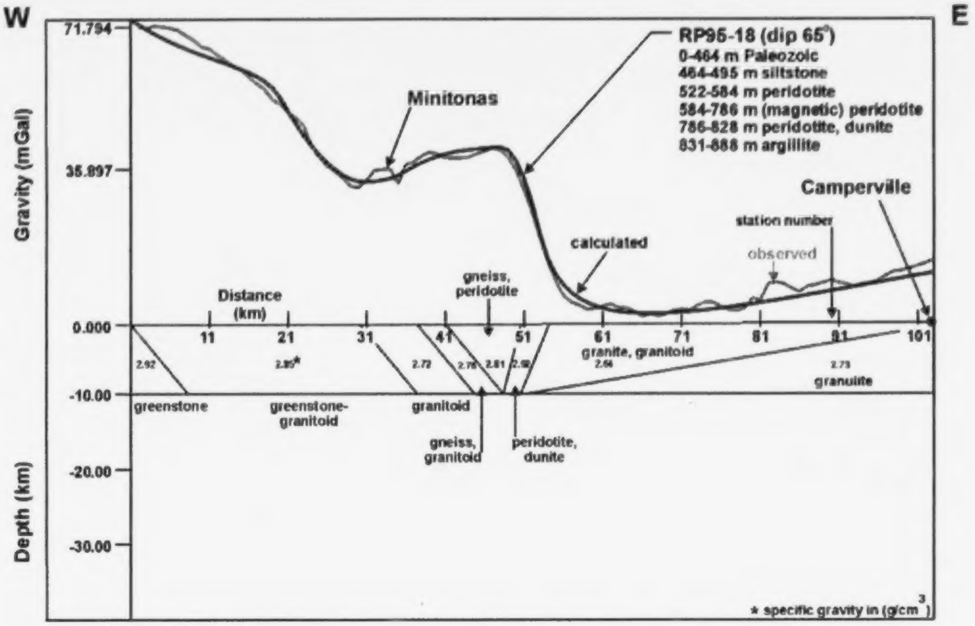


Figure GS-16-11: Gravity profile, with interpreted model, across the Camperville gravity low.

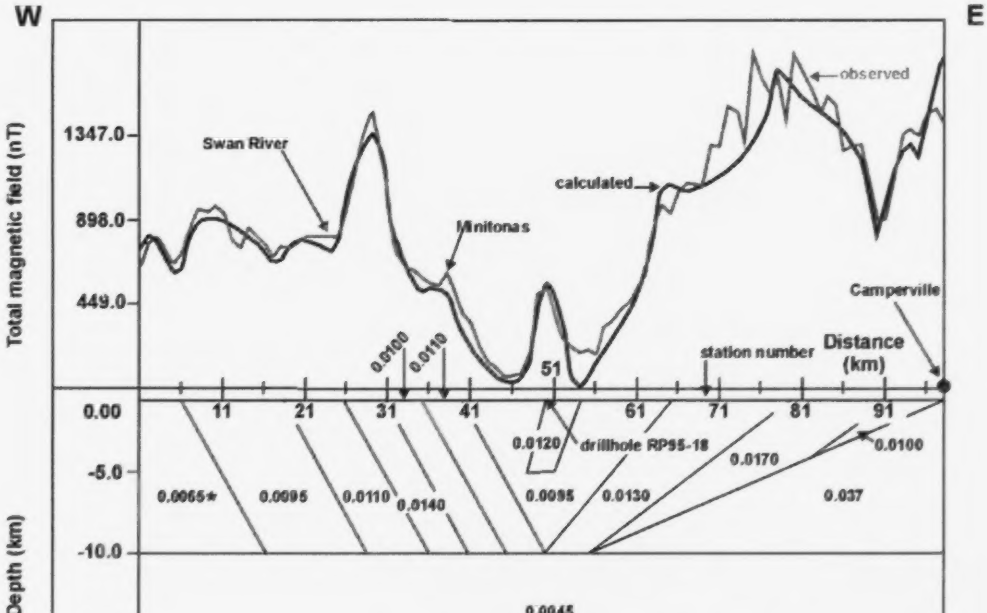


Figure GS-16-12: Magnetic profile, with interpreted model, across the Camperville gravity low.

(Fig. GS-16-2, GS-16-3) intersected a massive peridotite sill, as shown on Figure GS-16-11 (Assessment File 94638, Manitoba Industry, Trade and Mines, Winnipeg).

RECOMMENDATIONS AND CONCLUSIONS

There are similarities between the geophysical anomalies across the Thompson Nickel Belt and the data along The Pas Moraine traverse. The gravity trough, with coincident magnetic anomalies, presents the same model and therefore should be investigated. Deep penetrating electromagnetic surveys and ground magnetic surveys are recommended on strike (northeast) of the gravity low on The Pas Moraine. Flexures in the anomalies are areas for further investigation. Granges Exploration and Amax Exploration carried out Input™, Turam™ and ground magnetometer surveys on mineral reservations 119 and 120, which are on strike, toward the northeast, with the low gravity area of The Pas Moraine profile (Assessment File 92034, Manitoba Industry, Trade and Mines, Winnipeg). Two holes were drilled (Fig. GS-16-2) to test Turam™ conductors and intersected serpentinized peridotite. The remainder of the Turam™ conductors require further investigation. Preliminary Maps 2001FS-1 and 2001FS-2 (Thompson Nickel Belt Geology Working Group, 2001a, b), which encompass mineral reservations 119 and 120, show the principal rock types to be Archean basement migmatite gneiss and Pipe Formation ultramafic rocks with occasional iron formation.

The possible cause of the Camperville gravity low is a granitic intrusion with a high concentration of magnetite. The Pikwitonei granulite of the Superior Province forms a west–dipping, highly magnetic unit below the granitic intrusion.

ACKNOWLEDGMENTS

The authors would like to thank Alan Surasky for assisting in the gravity and magnetic surveys in 2000 and 2001. The Department of Geological Sciences at the University of Manitoba provided the gravity meter for both summers, and supported Alan's employment during the first summer.

Bonnie Lenton is gratefully acknowledged for preparing the figures used in this report, and Ruth Bezys and Herman Zwanzig are thanked for reviewing the manuscript.

REFERENCES

Bamburak, J.D., Hosain, I.T., Fedikow, M.A.F. and Dobrzanski, E. 2000: Camperville gravity low investigations (parts of NTS 62N/E and 63 C/E); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 202–209.

Bezys, R.K. and Conley, G.G. 1998: The Precambrian in Manitoba; Manitoba Energy and Mines, Stratigraphic Map Series, Opc-1, scale 1:2 000 000.

Cooper, G.R.J. 1998: GRAV2DC for Windows user's manual (version 2.05); Geophysical Department, University of The Witwatersrand, Johannesburg 2050, South Africa.

Cooper, G.R.J. 2000: MAG2DC for Windows user's manual (version 2.10); Geophysical Department, University of The Witwatersrand, Johannesburg 2050, South Africa.

Gibb, R.A. 1968: A geological interpretation of the Bouguer anomalies adjacent to the Churchill-Superior boundary in northern Manitoba; Canadian Journal of Earth Sciences, v. 5, p. 439–453.

Lucas, S.B., White, D.J., Bleeker, W., Hajnal, Z., Lewry, J. and Weber, W. 1996: Crustal structure of the Superior Boundary Zone (Thompson Belt) from new LITHOPROBE seismic reflection data; *in* Trans-Hudson Orogen Transect: Report of Sixth Transect Meeting, April 1–2, 1996, Saskatoon, LITHOPROBE Secretariat, University of British Columbia, LITHOPROBE Report No. 55, p. 82–94.

Roth, J. 1975: Exploration of the southern extension of the Manitoba Nickel Belt; Canadian Institute of Mining and Metallurgy Bulletin, v. 68, no. 761, p. 73–80.

Surasky, A.T. and Minkus, R.S. 2000: Gravity and magnetic profile from Camperville to the Saskatchewan border (parts of NTS 62N/E and 63C/E); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 210–213.

Surasky, A.T., Hosain, I.T. and Letkemen, A.J. 2001: Gravity and magnetic profile along The Pas Moraine; *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 164–171.

Thomas, M.D. and Tanczyck, E.I. 1994: Progress in gravity and magnetic analysis along the LITHOPROBE Trans-Hudson Orogen Transect; *in* Trans-Hudson Orogen Transect: Report of Fourth Transect Meeting, April 11–12, 1994, Saskatoon, LITHOPROBE Secretariat, University of British Columbia, Lithoprobe Report No. 38, p. 135–150.

Thompson Nickel Belt Geology Working Group 2001: Geology of Perch Lake (63G/5), Eating Point (63G/6), Howell Point (63G/11) and Bracken Lake (63G/12) areas; Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map 2001FS-1, scale 1:100 000.

Thompson Nickel Belt Geology Working Group 2001: Geology of Kokookahoo Island (63F/8) and Lamb Lake (63F/9) areas; Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Prelimary Map 2001FS-2, scale 1:100 000.

White, D., Boerner, D., Wu, J., Lucas, S., Berrer, E., Hannila, H. and Sommerville, R. 2000: Mineral exploration in the Thompson Nickel Belt, Manitoba, Canada, using seismic and controlled-source EM methods; Geophysics, vol. 65, no. 6, p. 1871–1881.

GS-17 PHANEROZOIC SOLID-SULPHIDE OCCURRENCE CONTAINING DEVONIAN DOLOMITE BRECCIA CLASTS, PEMMICAN ISLAND, LAKE WINNIPEGOSIS (NTS 63B12NW), MANITOBA

by J.D. Bamburak, I.T. Hosain and K. Klyne[1]

Bamburak, J.D., Hosain, I.T. and Klyne, K. 2002: Phanerozoic solid-sulphide occurrence containing Devonian dolomite breccia clasts, Pemmican Island, Lake Winnipegosis (NTS 63B12NW), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 131-143.

SUMMARY

J.B. Tyrrell noted iron-sulphide concretions in 1889 on the shoreline of Pemmican Island at the north end of Lake Winnipegosis. This summer, large solid-sulphide slabs, containing breccia clasts of sucrosic Devonian dolomite, were found just below the waterline. These slabs contain up to 1.18% Ni and 0.76% Zn. The island is a Protected Area, but the surrounding lake bottom has been staked.

Pemmican Island is situated at the eastern margin of the Precambrian Superior Boundary Zone, which cuts two subdomains of the Berens River Domain within the Archean Superior Province. The island is also at the northern edge of the Camperville gravity low. Basement reactivation during the Phanerozoic is thought have fractured the overlying Paleozoic carbonate rocks and provided avenues for fluid migration from depth.

Kaolin clay of the Cretaceous Swan River Formation has been found along the shoreline. The clay is believed to occupy a preglacial channel within the dolomite bedrock on the island. The interpreted channel, striking 070°, joins the East and South beaches, where the sulphide concretions have been found over localized areas. A fault zone beneath the channel is believed to have provided a path for iron-sulphide–rich fluids to reach and precipitate within the Devonian carbonate bedrock.

Numerous exploration companies have attempted to find buried Precambrian Thompson-type nickel-copper deposits to the north and west of Pemmican Island. Other companies have attempted to find Paleozoic Mississippi Valley–type lead-zinc deposits to the north and southwest of the island. On the basis of these new analytical results, more work is recommended in the vicinity of Pemmican Island to determine the possible presence of one or both of these deposit types.

INTRODUCTION

As early as 1889, iron-sulphide concretions were noted on Pemmican Island, located near the west shore at the north end of Lake Winnipegosis. Recently, concretions were found to contain up to 1.18% Ni and 0.76% Zn. These values are anomalous compared to Ni and Zn values from concretions found in Phanerozoic formations located elsewhere.

In 2000, all mineral rights on Pemmican Island were pending withdrawal from staking by Order of the Minister of Industry, Trade and Mines at the request of the Parks Branch. During the following year, Ken Klyne of Swan River staked 23 Ken claims (MB3069–3072, 3200–3207, 3236–3240 and 3272–3281) surrounding Pemmican Island, mainly in 27-43-18-W1 (NTS 63B12NW). Early in 2002, Pemmican Island Park Reserve was recorded in the Mining Recording Office. All mineral rights on the island were withdrawn.

GEOLOGICAL SETTING

Pemmican Island, shown in Figure GS-17-1, is an outlier of Devonian Winnipegosis Formation dolomite situated within the Silurian outcrop belt (Fig. GS-17-2). According to Norris et al. (1982, p. 31), the argillaceous dolomite on Pemmican Island is the Lower Member of the Winnipegosis Formation. The Winnipegosis Formation and underlying Phanerozoic units dip towards the southwest and are part of the Western Canada Sedimentary Basin.

The Precambrian basement forms the western margin of the Archean craton of the Superior Province and the northeast-trending Superior Boundary Zone (SBZ; Fig. GS-17-1). Two east-trending subdomains of the Berens River Domain also underlie the island, forming a T-shaped intersection with the SBZ (Pilkington and Thomas, 2001). Pemmican Island is also situated at the northern edge of the Camperville gravity low (Bamburak et al., 2000). Basement reactivation along the SBZ has been documented by Bezys (1996), Bezys et al. (1996), Bamburak (1999) and Bamburak et al. (2000).

Cretaceous Swan River Formation (Fig. GS-17-2) is draped on the eroded surface of the Devonian dolomite.

---

[1] Klyne Exploration, P.O. Box 184, Swan River, Manitoba R0L 1Z0

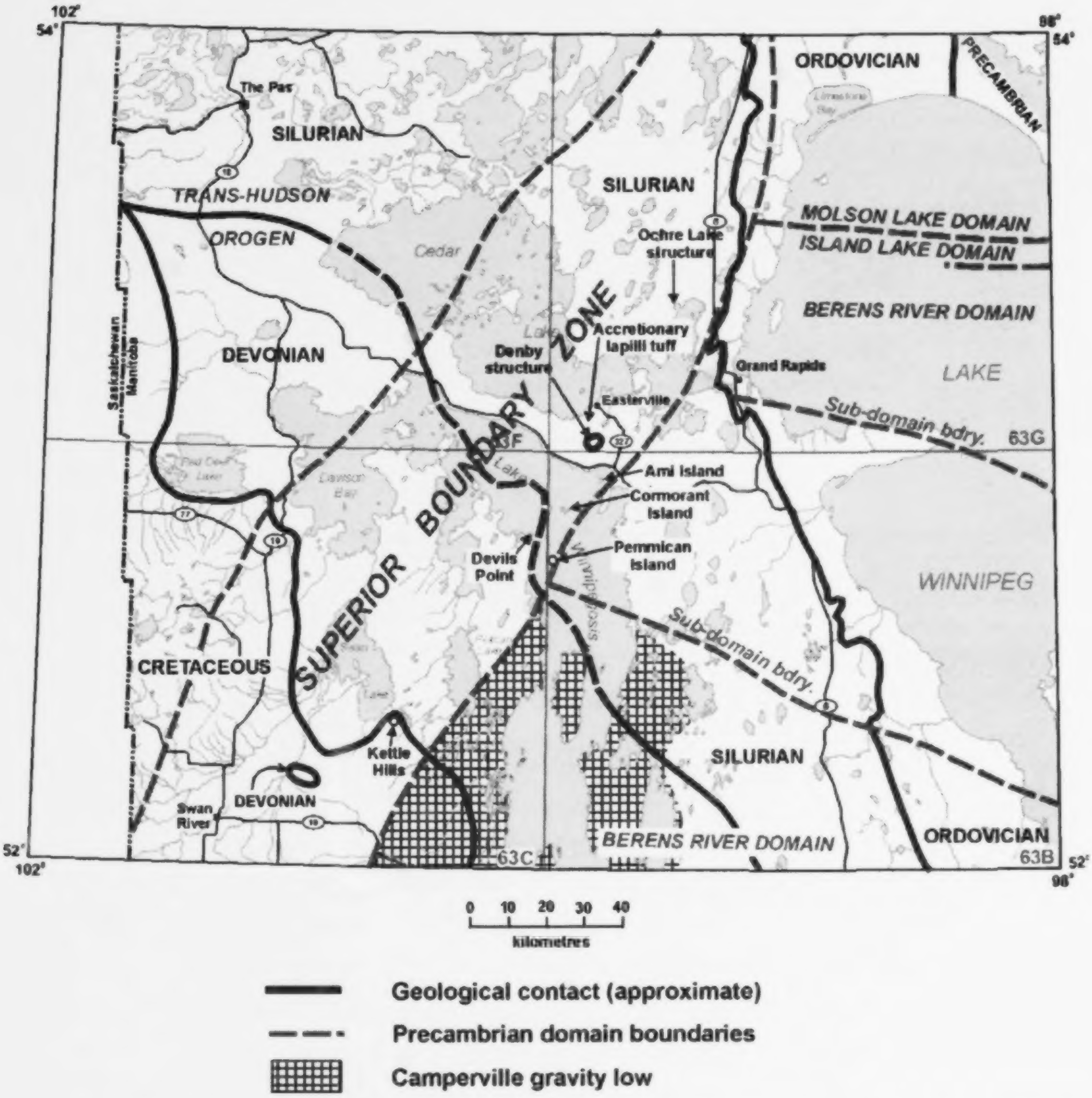

102°
54°
98°
54°
52°
102°
52°
98°
The Pas
SILURIAN
TRANS-HUDSON
OROGEN
Cedar
Lake
DEVONIAN
Saskatchewan
Manitoba
SILURIAN
Ochre Lake structure
Accretionary lapilli tuff
Denby structure
Easterville
SUPERIOR BOUNDARY ZONE
ORDOVICIAN
PRECAMBRIAN
MOLSON LAKE DOMAIN
ISLAND LAKE DOMAIN
BERENS RIVER DOMAIN
Grand Rapids
LAKE
Sub-domain bdry.
63G
63F
Ami Island
Cormorant Island
Pemmican Island
Devils Point
Dawson Bay
Red Deer Lake
WINNIPEG
Sub-domain bdry.
CRETACEOUS
SILURIAN
Kettle Hills
Swan River
DEVONIAN
BERENS RIVER DOMAIN
ORDOVICIAN
63C
63B
0 10 20 30 40
kilometres
Geological contact (approximate)
Precambrian domain boundaries
Campervillle gravity low

Figure GS-17-1: Geological setting of Pemmican Island, related features and immediate vicinity at the north end of Lake Winnipegosis. Precambrian domain boundaries after Pilkington and Thomas (2001).

Pleistocene glacial till and lacustrine sediments overlie the Swan River beds except along the shoreline, where Recent boulders, cobbles and sand are reworked annually by ice push and subsequent wave action.

PREVIOUS WORK

In the summer of 1889, J.B. Tyrrell visited Pemmican Island. Tyrrell documented the presence of nodules of marcasite and fragments of lignite, associated with white sandstone. He interpreted this to be a Cretaceous "outlier of Dakota sandstone deposited in a hollow of the Devonian rocks" (Tyrrell, 1892, p. 170E).

Later, Tyrrell (1890, p. 228) described the distribution of what he believed to be the 'Dakotah Group' (now known as the Swan River Formation) as follows:

> "The terrane can be seen in several exposures along the foot of the northern portion of the Cretaceous escarpment, and at a small island known as Pemican Island in lake Winnipegosis, forty-four miles east from the foot of the escarpment there are evidences of the presence of this or the overlying group. The exposures seen were altogether

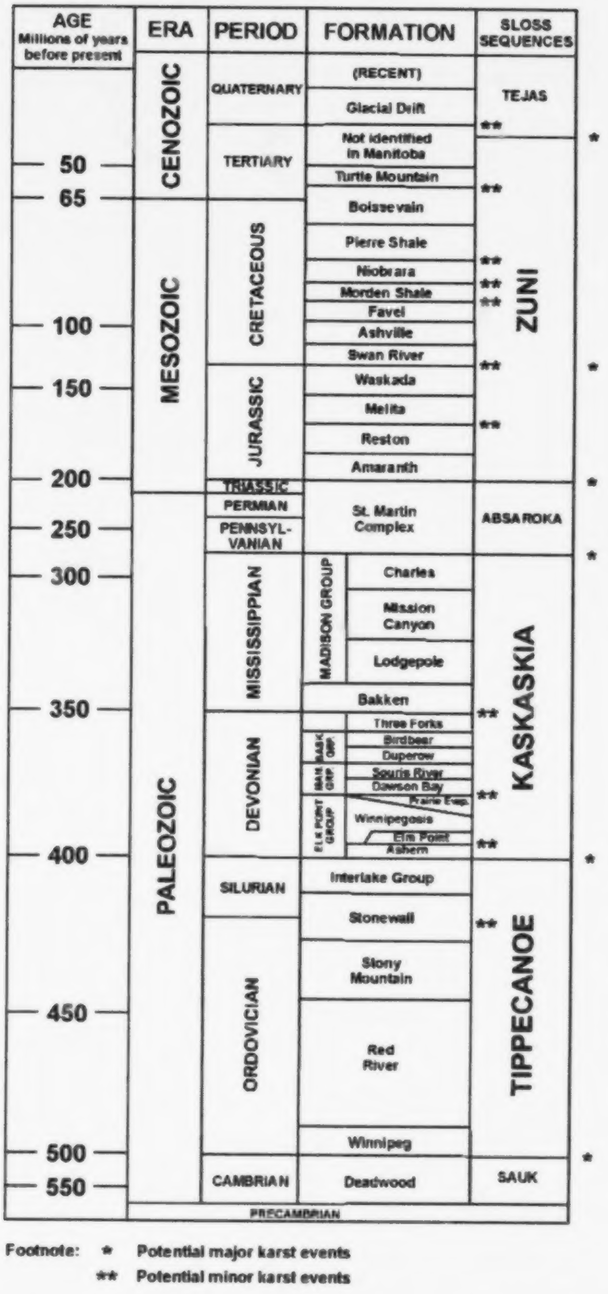

AGE
Millions of years before present
ERA
PERIOD
FORMATION
SLOSS SEQUENCES
CENOZOIC
QUATERNARY
(RECENT)
Glacial Drift
TEJAS
TERTIARY
Not identified in Manitoba
Turtle Mountain
50
65
MESOZOIC
CRETACEOUS
Boissevain
Pierre Shale
Niobrara
Morden Shale
Favel
Ashville
Swan River
ZUNI
100
150
JURASSIC
Waskada
Melita
Reston
Amaranth
200
TRIASSIC
PERMIAN
PENNSYL-VANIAN
St. Martin Complex
ABSAROKA
250
300
PALEOZOIC
MISSISSIPPIAN
MADISON GROUP
Charles
Mission Canyon
Lodgepole
Bakken
KASKASKIA
350
DEVONIAN
Three Forks
SASK GRP
Birdbear
Duperow
MAN GRP
Souris River
Dawson Bay
ELK POINT GROUP
Prairie Evap.
Winnipegosis
Elm Point
Ashern
400
SILURIAN
Interlake Group
Stonewall
TIPPECANOE
ORDOVICIAN
Stony Mountain
Red River
450
Winnipeg
500
CAMBRIAN
Deadwood
SAUK
550
PRECAMBRIAN
**
*
Footnote: * Potential major karst events
** Potential minor karst events

Figure GS-17-2: Generalized stratigraphic section for southern Manitoba, with asterisks showing times of karst events (McRitchie, 1991).

too few and small to allow of any exact determination being made of the total thickness of the group, but on account of the irregularities of the floor on which it was laid down it certainly varies greatly even in short distances. Near the northwest end of Lake Winnipegosis it has probably a maximum thickness of two hundred feet, while on the north side of the Riding Mountain, where it was passed through in the Manitoba Oil Co's well on Vermillion River, it has, so far as can be determined from the few specimens at hand, a thickness of fifty-five feet."

Similar concretions were also described on Ami Island, Devils Point and Cormorant Island, at the north end of

Lake Winnipegosis (Fig. GS-17-1) by Tyrrell (1892, p. 153E, 170E and 171E, respectively). On Ami Island, Tyrrell noted "small rounded masses of white sandstone holding nodules of Marcasite". Tyrrell also speculated that the nodules or concretions had been ice pushed from the bottom of Lake Winnipegosis.

In 1964, A.W. Norris and M. Oullet noted "numerous loose fragments of iron sulphide" on the northeast shore of Pemmican Island, 0.32 km northwest of the east tip of the island (Norris et al., 1982, p. 31). Norris and Oullet also measured two sections along a cliff face, 0.16 and 0.38 km west of the east tip of the island. The sections extended to heights of 5.0 and 8.5 m above lake level, respectively, and consisted of argillaceous dolomite of the Lower Member of the Devonian Winnipegosis Formation. The dolomite beds exposed in the cliff were estimated to be within 6 m of the base of the formation, and the underlying Devonian Ashern Formation is believed to be present near the edge of the lake (Norris et al., 1982, p. 31, 165). Baillie (1950) could not find any evidence of the Ashern Formation at the base of Pemmican Island.

Numerous exploration companies have attempted to find buried Precambrian Thompson-type nickel-copper deposits to the north and west of Pemmican Island. McRitchie (1995) and Hosain and Bamburak (GS-16, this volume) documented the results of exploration along the southwest extension of the Thompson Nickel Belt, beginning in the 1970s. Other companies have attempted to find Paleozoic Mississippi Valley–type (MVT) lead-zinc deposits to the north and southwest of the island (Bamburak et al., 2000).

In 1970, Cominco Ltd. attempted to locate MVT deposits in the vicinity of Denbeigh Point (Fig. GS-17-1), 12 km northeast of Pemmican Island and 8 km south of Easterville (Assessment File 91785, Manitoba Industry, Trade and Mines, Winnipeg). Cominco was attracted to the area by the reported occurrence of "massive botryoidal marcasite". The occurrence "was considered as encouragement with regard to Pb-Zn mineralization in the Paleozoic section." In October of the same year, Cominco reported that "Despite the fact that islands and the shoreline around the Denbeigh Peninsula were intensively searched, no evidence was found of marcasite mineralization, in either float or outcrop." Due to drilling, however, this work resulted in the discovery of the Denby structure, an anomalous Precambrian basement high close to a Cretaceous "channel or karst deposit" with limestone boulders that contained a large amount of marcasite (McCabe, 1978; Bezys et al., 1996).

Cominco's investigations, this time for Ni-Cu mineralization, resumed in the late 1990s (Assessment Files 94638 to 94643, Manitoba Industry, Trade and Mines, Winnipeg). Most of the drilling was done to the north, west and southwest of Pemmican Island, and as far south as the Kettle Hills (Fig. GS-17-1). Although not successful in locating an economic deposit, the drilling did result in the discovery of an accretionary lapilli tuff within Cretaceous channel fill in drillhole RP-96-21, south of Easterville (Bezys et al., 1996). The Denby structure, mentioned above, is 5 km southeast of this hole.

Bezys (1996) noted disturbed Silurian bedrock at Ochre Lake (Fig. GS-17-1), on strike with the sulphide occurrences described by Tyrrell (1890, 1892) and the lapilli tuff and Denby structure (described above). Ochre Lake is approximately 70 km northeast of Pemmican Island. Bezys interpreted that the structurally disturbed in situ carbonate beds represented a fault-controlled feature or a diatreme structure.

Mineralized Swan River Formation core, from the Survey's stratigraphic drillholes and from holes drilled by private companies, has been sampled and analyzed (Fedikow et al., 1998).

CURRENT STUDY

In May 2001, Ken Klyne of Swan River, Manitoba contacted the Manitoba Geological Survey to report the presence of numerous sulphide cobbles on the east beach of Pemmican Island in Lake Winnipegosis. A visit was made to Swan River to view the samples, and a trip was subsequently made to Pemmican Island in 2001. Geological and geophysical investigations were carried out over two days at three sites on the east and south shoreline of Pemmican Island (Fig. GS-17-3). In July 2002, a second opportunity to visit Pemmican Island, as well as Ami Island (at the north end of Lake Winnipegosis, near Denbeigh Point), was provided.

Sulphide beach east

Station no. 99-01-PI-001 (SE-27-43-18-W1; UTM 14U, 433501E, 5842619N, NAD 27)

Iron-sulphide concretions are present along a north-trending shoreline on the east side of Pemmican Island (Fig. GS-17-3). The angular, reddish-brown concretions, ranging in size from pebbles to boulders, lie in an unconsolidated sandy matrix between typical, well-rounded, Precambrian and Paleozoic cobbles and boulders (Fig. GS-17-4, GS-17-5). In September 2001, the iron-sulphide concretions were found within a zone measuring 28 m in length (parallelling the shore) and 2 m in width. A weak EM-16 anomaly corresponded to the mineralized section of the beach.

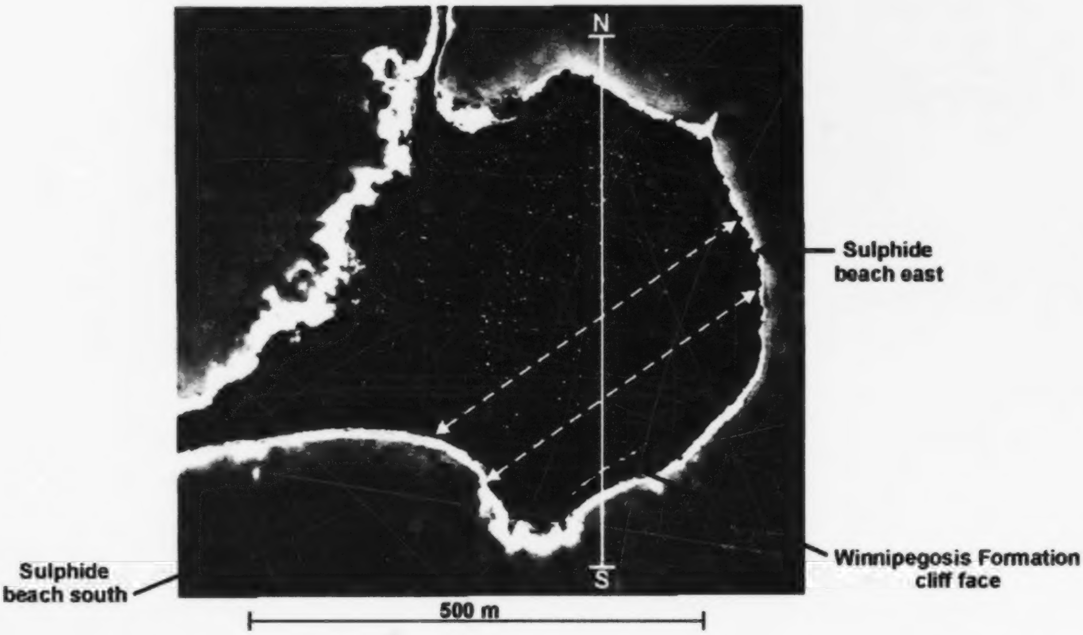

N
Sulphide beach east
Winnipegosis Formation cliff face
S
Sulphide beach south
500 m

Figure GS-17-3: Pemmican Island, showing sample sites, interpreted northeast-trending karst channel (shown between white dashed lines) and north-south line of section (shown in Fig. GS-17-9).

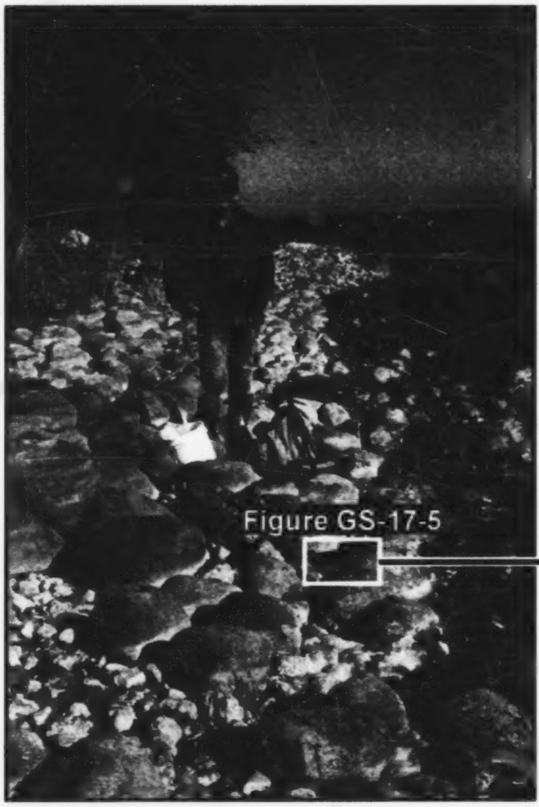
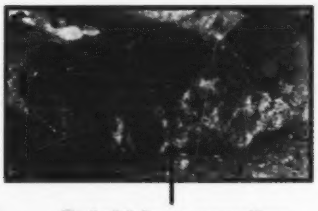


Figure GS-17-5

Figure GS-17-4: Ken Klyne and iron-sulphide concretions, Sulphide beach east.

Figure GS-17-5: Close-up of iron-sulphide concretion, Sulphide beach east.


Sulphide concretion

In July 2002, with falling lake levels, the width of the exposed zone increased by another 2 m. Within this newly exposed area, iron-sulphide concretions (many containing irregular clasts of dolomite) formed up to 80% of the surface. Further investigation, 1 m below the current lake level and parallel to the exposed zone, disclosed many large, solid-sulphide slabs (Fig. GS-17-6, GS-17-7). Some of the slabs ranged in size up to 40 cm by 40 cm by 15 cm and weighed 30 to 50 kg. They were located within fine silt, up to 4 m away from the shoreline.

Winnipegosis Formation bedrock is exposed in thin slabs on the beach and may be continuous within the cliff. The formation consists of sucrosic dolomite, which is similar to the clasts within some of the iron-sulphide concretions.

Devonian Winnipegosis Formation dolomite cliff

Station no. 99-01-PI-002 (SE-27-43-18-W1; UTM 14U, 433345E, 5842396N, NAD 27)

Vuggy sucrosic dolomite is present in a 3 m high, east-northeast-trending cliff of Devonian Winnipegosis Formation along the southeast shore of Pemmican Island (Fig. GS-17-3). Karst-like channels, plunging 70°SE, cut diagonally downward on the face of the cliff. The top of the cliff is vegetated and the plant roots utilize the vuggy

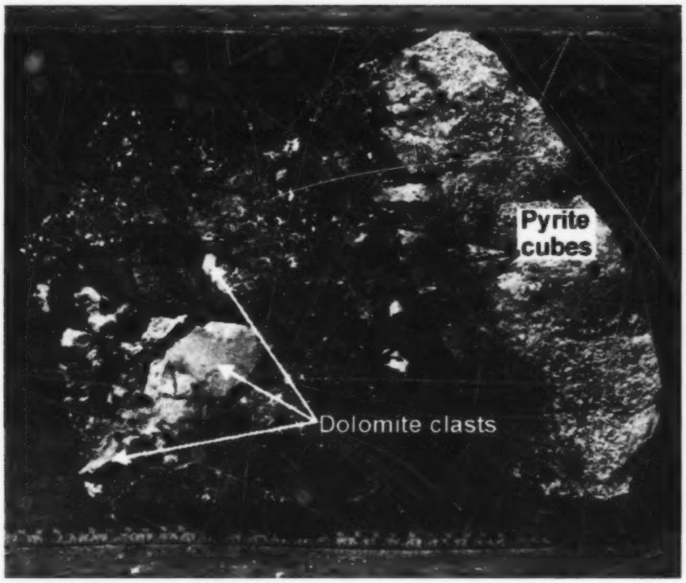


Figure GS-17-6: Solid-sulphide concretion with dolomite clasts and pyrite cubes, Sulphide beach east.

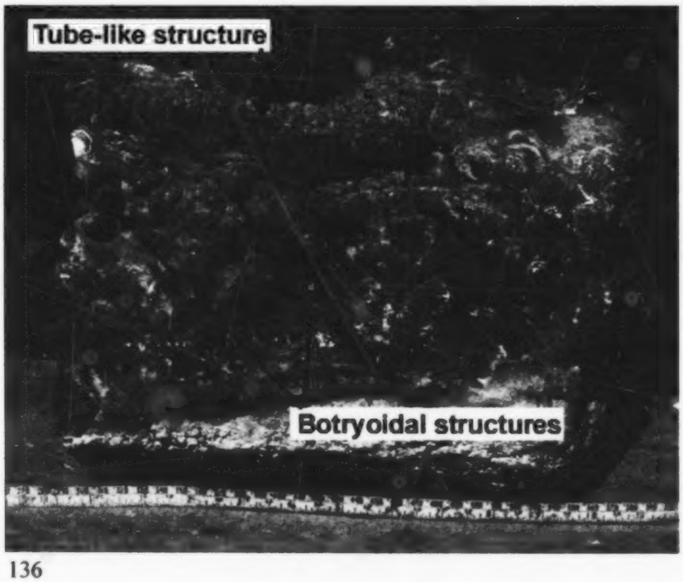


Figure GS-17-7: Solid-sulphide concretion with botryoidal and tube-like structures, Sulphide beach east.

dolomite for water. No fracture pattern is evident and no rusty appearance is present on the cliff face of the dolomite.

Sulphide beach south

Station no. 99-01-PI-002 (SE 27-43-18-W1; UTM 14U, 433307E, 5842446N, NAD 27)

Iron-sulphide pebbles and lignite fragments are interspersed between cobble-sized erratics on an east-trending shoreline on the south side of Pemmican Island (GS-17-3). A strong EM-16 anomaly corresponds to the mineralized section of the beach. Underlying the cobbles, pebbles and sand on the beach is a relatively pure, cream-coloured kaolin clay (Fig. GS-17-8), probably of the Cretaceous Swan River Formation. The clay is topographically lower than the dolomite cliff (described above) and is at about the same elevation as the dolomite bedrock on the East beach.

Chemical analyses

The results of chemical analyses done on Pemmican Island samples, provided by Ken Klyne, are shown in Tables GS-17-1 and GS-17-2. Most samples were collected at Sulphide beach east (Klyne's site 1), and a few at the Sulphide beach south (Klyne's site 2). The analytical work was done at Activation Laboratories Limited (Actlabs) in Ancaster, Ontario and at TSL Laboratories in Saskatoon, Saskatchewan.

A sample from station no. 99-01-PI-001 (described above) was sent to Actlabs by the Manitoba Geological Survey in February 2002, and the analysis is also included in Table GS-17-1.

Analytical results below the level of detection, or those covered by another method, were deleted from Table GS-X-1. The elements Ag, Ba, Br, Ca, Cs, Ir, Mo, Ni, Rb, Sn, Sr, Ta, U, Tb and Yb were removed for INAA, and Be for ICP.

DISCUSSION

- All of the sulphide-concretion occurrences noted by Tyrrell (1890, 1892) at the north end of Lake Winnipegosis, including Pemmican Island, are aligned with the eastern margin of the underlying northeast-trending Superior Boundary Zone. The occurrences are on strike with: the Denby structure, an anomalous Precambrian basement high described by McCabe (1978); the fault-controlled or diatreme Ochre Lake structure of Bezys (1996); and accretionary lapilli within Cretaceous channel fill of Bezys et al. (1996). It should be noted, however, that the sulphide concretions described by Tyrrell in 1889 could not be found in 2002 on the shoreline of Ami Island.
- Pemmican Island lies very close to the T-intersection between two subdomains of the Berens River Domain and the Superior Boundary Zone (Fig. GS-17-1). The northwest trend of the common margin of the subdomains roughly

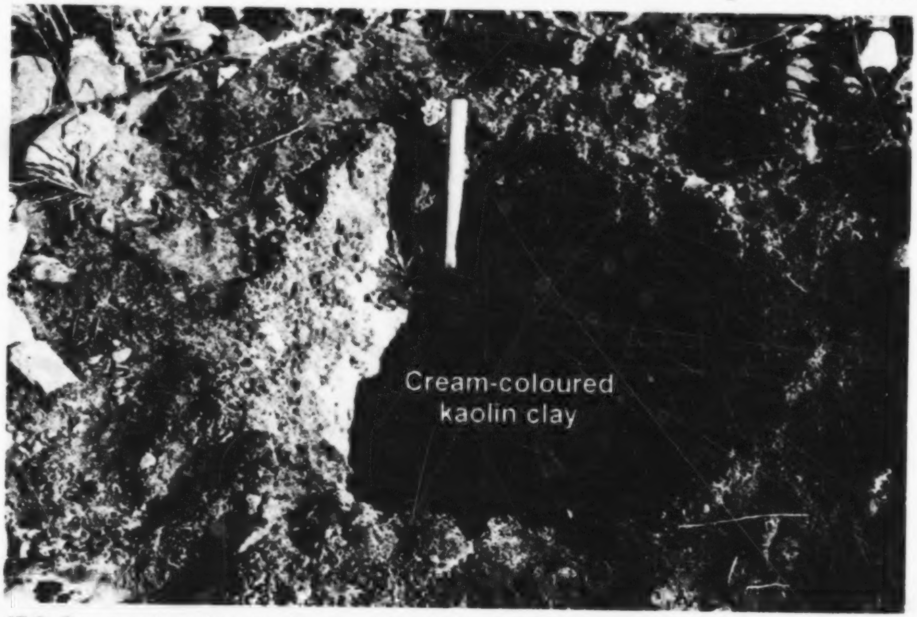


Figure GS-17-8: Cream-coloured kaolin clay beneath cobbles, Sulphide beach south.

Table GS-17-1: Ken Klyne's Pemmican Island sulphide-concretion analyses (by instrumental neutron activation analysis [INAA] and inductively couple plasma–mass spectrometry [ICP-MS]).

Element	Au	As	Co	Cr	Fe	Hf	Hg	Na	Sb	Sc	Se	Th	W	La	Ce	Sm	Eu	Lu
Units	PPB	PPM	PPM	PPM	%	PPM	PPM	%	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM
Method	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA	INAA
Activation Laboratories Ltd.																		
Detection Limit	**2**	**0.5**	1	5	**0.01**	**1**	**1**	**0.01**	**0.1**	**0.1**	**3**	**0.2**	**1**	**0.5**	**3**	**0.1**	**0.2**	**0.05**
22203-1	-2	1120	50	13	43.4	-1	-1	-0.01	7.4	-0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22203-2	-2	3670	73	13	45.5	-1	-1	0.01	1.1	-0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22203-3	-2	857	15	11	45.3	-1	-1	0.01	1	0.2	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22203-4	6	1610	130	7	41.3	-1	-1	0.02	17	0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22203-5	-2	2270	160	14	46.7	-1	-1	0.01	22.3	0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22203-6	-2	1220	49	20	45.6	-1	-1	0.01	6.4	0.1	-3	0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22367-1	-2	1230	3	9	42.3	-1	-1	-0.01	-0.2	-0.1	-3	0.6	-1	-0.5	-3	-0.1	-0.2	-0.05
22367-2	-2	1780	120	17	53.2	-1	-1	0.01	15.3	-0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22367-3	-2	833	25	13	41.4	-1	-1	-0.01	-0.1	-0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22367-4	-2	3300	79	11	46.2	-1	-1	-0.01	-0.3	-0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22429-1	-2	1980	174	14	45.2	-1	-1	-0.01	8.3	-0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22429-2	-2	1170	350	-5	48.1	-1	-1	-0.01	18.7	-0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22429-3	-2	1540	813	-5	52.1	-1	-1	-0.01	13	-0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22512-1	-2	1470	64	-5	61.7	-1	-1	0.02	3.3	0.3	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22512-2	-2	2570	64	25	62.2	-1	-1	0.02	3.5	0.4	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
22598-1	-2	2070	21	15	50.2	-1	3	0.01	-0.1	0.1	-3	-0.2	2	-0.5	-3	-0.1	-0.2	-0.05
22598-2	-2	2240	55	14	43.9	-1	1	-0.01	-0.1	-0.1	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
23025-2	-5	5620	382	-5	52.8	-1	-1	0.02	2.8	1.9	-3	-0.6	-1	1.5	-3	-0.1	-0.2	-0.05
23025-3	-5	154	6	25	23.8	4	-1	0.02	8.1	1.6	-3	1	-1	4	-3	0.7	-0.2	-0.05
23025-4	-5	303	8	30	50.8	-1	-1	0.03	5.1	1.9	17	1.4	-1	8.3	-3	0.6	-0.2	0.16
23025-5	-5	450	8	27	45.8	-1	-1	0.06	4.3	2.5	-3	-0.3	-1	9.1	12	4	0.3	-0.05
99-01-PI-001	8	1740	165	12	46.4	-1	-1	-0.01	19	0.2	-3	-0.2	-1	-0.5	-3	-0.1	-0.2	-0.05
TSL Laboratories																		
Detection Limit		**1**	**1**	**1**	**0.01**			**0.01**	**1**	**1**			1					
S10928-2		1520	38	138	28.8			<0.01	3	<1			<1					
S10928-3		198	4	464	18.5			<0.01	2	<1			<1					
S10928-4		150	2	172	26.8			<0.01	3	<1			<1					
S10928-5		357	2	63	29.2			<0.01	3	<1			<1					

Note: S10928-2 to -5 are sample duplicates of 23025-2 to -5, above. Analysis was by aqua regia digestion with an ICP-MS finish.

Table GS-17-1: Ken Klyne's Pemmican Island sulphide-concretion analyses (by instrumental neutron activation analysis [INAA] and inductively couple plasma–mass spectrometry [ICP-MS]). (continued)

Element	Mass	Ag	Cd	Cu	Mn	Mo	Ni	Pb	Zn	Al	Bi	Ca	K	Mg	P	Sr	Ti	V
Units	g	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	%	PPM	%	%	%	%	PPM	%	PPM
Method	INAA	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP
Activation Laboratories Ltd.																		
Detection Limit		**0.3**	**0.3**	**1**	**1**	**1**	**1**	**3**	**1**	**0.01**	**2**	**0.01**	**0.01**	**0.01**	**0.001**	**1**	**0.01**	**2**
22203-1	48.02	-0.3	2.7	6	337	118	565	19	24	0.11	-2	0.02	-0.01	0.03	0.003	2	-0.01	-2
22203-2	43.99	-0.3	1.5	2	23	68	699	32	83	0.01	-2	0.12	0.02	0.02	0.002	3	-0.01	-2
22203-3	49.16	-0.3	2.1	-1	429	219	191	-3	21	0.29	-2	-0.01	-0.01	0.04	0.004	3	0.02	4
22203-4	49.01	-0.3	1.7	-1	107	82	1518	24	21	0.10	-2	0.02	-0.01	0.04	0.006	3	-0.01	-2
22203-5	40.04	-0.3	2.3	-1	77	85	1737	35	21	0.12	-2	-0.01	-0.01	0.02	0.004	3	-0.01	-2
22203-6	46.21	-0.3	2.1	-1	360	152	515	-3	26	0.04	-2	0.24	-0.01	0.06	0.002	6	-0.01	-2
22367-1	41.53	-0.3	0.7	-1	30	47	45	-3	10	0.12	-2	-0.01	-0.01	-0.01	-0.001	3	-0.01	-2
22367-2	15.62	-0.3	-0.3	-1	172	104	1020	30	27	0.29	-2	0.02	0.03	-0.01	-0.001	5	-0.01	-2
22367-3	49.53	-0.3	0.6	-1	164	157	287	22	20	0.11	-2	-0.01	0.01	0.02	-0.001	2	-0.01	-2
22367-4	22.11	-0.3	1.4	-1	35	84	681	20	48	0.01	-2	-0.01	-0.01	-0.01	0.001	-1	-0.01	-2
22429-1	8.295	-0.3	-0.3	8	159	94	1470	6	26	0.02	-2	-0.01	0.01	-0.01	0.002	-1	-0.01	-2
22429-2	6.658	-0.3	-0.3	4	69	64	2832	59	34	0.02	-2	-0.01	0.01	-0.01	0.002	-1	-0.01	-2
22429-3	5.84	-0.3	0.3	6	132	84	2125	16	40	0.01	-2	-0.01	-0.01	-0.01	0.002	-1	-0.01	-2
22512-1	12.79	-0.3	0.8	9	96	61	435	-3	17	0.10	-2	0.04	0.01	-0.01	-0.001	4	-0.01	-2
22512-2	13.25	-0.3	1	14	92	58	471	-3	15	0.14	-2	0.04	0.01	-0.01	-0.001	5	-0.01	-2
22598-1	5.31	-0.3	-0.3	13	82	90	150	-3	25	0.01	-2	-0.01	0.01	-0.01	-0.001	1	-0.01	-2
22598-2	15.34	-0.3	-0.3	3	62	84	273	-3	28	0.01	-2	-0.01	0.01	-0.01	-0.001	-1	-0.01	-2
23025-2	12.54	0.3	3.2	33	51	76	2710	13	107	0.03	36	0.10	-0.01	-0.01	-0.001	3	-0.01	-2
23025-3	23.85	-0.3	0.5	32	26	19	235	196	5	0.34	18	0.08	0.02	0.02	0.001	7	0.10	5
23025-4	14.17	-0.3	5.7	10	12	111	24	54	1	0.27	32	0.09	-0.01	-0.01	0.001	7	0.04	2
23025-5	15.85	-0.3	2.4	27	21	58	21	43	-1	0.2	32	0.08	-0.01	0.06	0.003	8	0.02	3
99-01-PI-001	49.32	0.4	3.3	16	142	84	1559	16	44	0.21	9	0.10	0.08	-0.01	0.002	3	-0.01	-2
TSL Laboratories																		
Detection Limit		**0.2**	**1**	**1**	**10**	**2**	**1**	**2**	**1**	**0.01**	**1**	**0.01**	**0.01**	**0.01**	**10**	**1**	**0.01**	**1**
S10928-2		1.2	<1	40	21	44	330	11	163	<0.01	<1	0.06	<0.01	0.02	43	1	<0.01	35
S10928-3		0.7	<1	29	42	24	79	215	5	<0.01	<1	0.21	<0.01	0.02	25	4	<0.01	22
S10928-4		0.8	<1	10	9	101	31	76	9	<0.01	<1	0.04	<0.01	<0.01	40	4	<0.01	33
S10928-5		0.7	<1	8	<10	60	18	74	4	<0.01	<1	0.04	<0.01	0.01	49	3	<0.01	34

Note: S10928-2 to -5 are sample duplicates of 23025-2 to -5, above. Analysis was by aqua regia digestion with an ICP-MS finish.

Table GS-17-1: Ken Klyne's Pemmican Island sulphide-concretion analyses (by instrumental neutron activation analysis [INAA] and inductively couple plasma–mass spectrometry [ICP-MS]). (continued)

Element	**Y**	**S**	**Sample type**	**Site**	**Easting**	**Northing**
Units	**PPM**	**%**				
Method	**ICP**	**ICP**				
Activation Laboratories Ltd.						
Detection Limit	**1**					
22203-1	-1	33.555	Single concretion	1	433501	5842619
22203-2	-1	34.538	Single concretion	1	433501	5842619
22203-3	-1	34.123	Single concretion	1	433501	5842619
22203-4	-1	32.807	Single concretion	1	433501	5842619
22203-5	-1	33.262	Single concretion	1	433501	5842619
22203-6	-1	33.348	Single concretion	1	433501	5842619
22367-1	-1	30.732	Single concretion	1	433501	5842619
22367-2	2	30.979	Single concretion	1	433501	5842619
22367-3	-1	31.172	Single concretion	1	433501	5842619
22367-4	-1	30.926	Single concretion	1	433501	5842619
22429-1	-1	26.561	Single concretion	1	433501	5842619
22429-2	-1	28.530	Single concretion	1	433501	5842619
22429-3	-1	26.840	Single concretion	1	433501	5842619
22512-1	-1	31.865	Single concretion	1	433501	5842619
22512-2	1	32.359	Single concretion	1	433501	5842619
22598-1	-1	33.381	Single concretion	1	433501	5842619
22598-2	1	30.645	Single concretion	1	433501	5842619
23025-2	-1	30.121	Composite sample	1	433501	5842619
23025-3	2	19.060	Composite sample	2	433345	5842396
23025-4	2	26.480	Composite sample	1	433501	5842619
23025-5	-1	26.374	Composite sample	2	433345	5842396
99-01-PI-001	-1	36.440	Single concretion	1	433501	5842619
TSL Laboratories						
Detection Limit	**1**					
S10928-2	<1	nil	Composite sample	1	433501	5842619
S10928-3	<1	nil	Composite sample	2	433345	5842396
S10928-4	1	nil	Composite sample	1	433501	5842619
S10928-5	<1	nil	Composite sample	2	433345	5842396

Note: S10928-2 to -5 are sample duplicates of 23025-2 to -5, above. Analysis was by aqua regia digestion with an ICP-MS finish.

corresponds to the northern edge of the Camperville gravity low. The 070° direction of the interpreted karst channel and dolomite cliff on the southeast shore of Pemmican Island may represent differential basement reactivation between the Superior Boundary Zone, the Camperville gravity low and the subdomain boundary.

- A karst channel (Fig. GS-17-3), striking 070°, is interpreted between the iron-sulphide–rich area on Sulphide beach east (Station PI-001) and that on Sulphide beach south (Station PI-003). The channel is north of and parallel to the strike of the Winnipegosis Formation dolomite cliff at Station PI-002. The bottom of the channel is near lake level on Sulphide beach east. The channel seems to plunge towards Sulphide beach south, where it is filled with kaolin clay of probable Cretaceous age. Figure GS-17-9 shows a composite cross-section from south to north across Pemmican Island, approximately halfway between the two beaches. A fault zone is interpreted to underlie the karst channel, which could provide a means for mineralizing fluids from depth to reach the Devonian carbonate rocks.
- Maximum analytical values obtained from single concretions, shown in Tables GS-17-1 and GS-17-2, are: 62.2% Fe, 36.4% S, 1.18% Ni, 0.76% Zn, 3670 ppm As, 1100 ppm Pb and 813 ppm Co. It should be noted that the sample with 1100 ppm Pb also contained 1700 ppm Zn.
- Composite sample 23025-2, consisting of pebbles taken from the East beach by Ken Klyne, contained 52.8% Fe, 30.12% S, 0.45% Ni, 5620 ppm As and 382 ppm Co. Since this sample had values much higher than many of the single concretion samples, it is likely that at least one pebble must have had significantly higher values than the rest.
- Portions of the sulphide samples collected on Pemmican Island are weathered and the resulting iron-oxide–rich cement has incorporated more recent materials (e.g., limestone and granite pebbles, and sand) into a reddish oxide matrix surrounding some of the nodules or concretions. The reddish matrix that colours the beaches may account for the previous interpretation by Baillie (1950) that the Devonian Ashern Formation is present near the base of

Table GS-17-2: Ken Klyne's Pemmican Island sulphide-concretion analyses (by aqua regia digestion and atomic absorption [AA] finish).

Element	Ni	Ni	Zn	Zn	Cu	Pb
Units	**PPM**	**%**	**PPM**	**%**	**PPM**	**PPM**
TSL Laboratories						
Detection Limit	**1**	**0.01**	**1**	**0.01**	**1**	**1**
S11617-1	270		8		3	2
S11617-2	89		140		4	25
S11617-3	1320		140		2	60
S11617-4	330		16		1	6
S11617-5	200		11		1	7
S11617-6	770		1000		3	85
S11617-7	140		11		3	1
S11617-8	610		16		1	15
S11617-9	520		1180		3	270
S11617-10	270		14		3	14
S11617-11	280		31		1	22
S11617-12	160		280		11	63
S11617-13	320		22		1	9
S11617-14	290		11		1	10
S11617-15	200		180		2	36
S11617-16	20		18		4	7
S11617-17	360		87		3	23
S11617-18	58		75		3	15
S11617-19	200		9		1	7
S11617-20	270		9		1	6
S11617-21	250		800		13	28
S11617-22	1330		23		4	51
S11617-23	1350		51		10	57
S11617-24	1160		1720		18	1100
S11617-25	330		820		5	36
S11617-26	310		610		8	75
S11617-27	>5000	1.18	>5000	0.54	12	540
S11617-28	330		1260		9	26
S11617-29	2410		5000	0.50	9	190
S11617-30	350		73		5	17
S11617-31	240		18		2	2
S11700-1	430		560		20	44
S11700-2	1940		1630		11	130
S11700-3	440		>5000	0.76	16	300
S11700-4	390		73		2	24
S11700-5	210		270		3	18
S11700-6	51		26		1	<1
S11700-7	55		86		8	6

Extraction for ppm analyses by HCl-HNO_3 and for % analyses by HNO_3-HF-$HClO_4$-HCl

Pemmican Island.

- Many of the iron-sulphide concretions are coated with a caliche crust of calcium carbonate, which gives them a beige appearance.

RECOMMENDATIONS

- A shallow drilling program should be carried out beneath the water to a depth of 60 m, adjacent to Sulphide beach east, to determine if mineralization continues to depth.
- A ground electromagnetic survey should be conducted, on the ice adjacent to Pemmican Island, to determine whether any anomalies are present near the triple point at the junction between the two subdomains of the Berens River Domain and the Superior Boundary Zone. Follow-up drilling should be done through the Paleozoic rocks into the underlying Precambrian basement.
- A magnetic survey should also be carried out to determine if there are any Precambrian basement Thompson-type nickel anomalies within the Superior Boundary Zone in the vicinity of Pemmican Island. However, the testing of any resulting anomalies will require much deeper drilling.

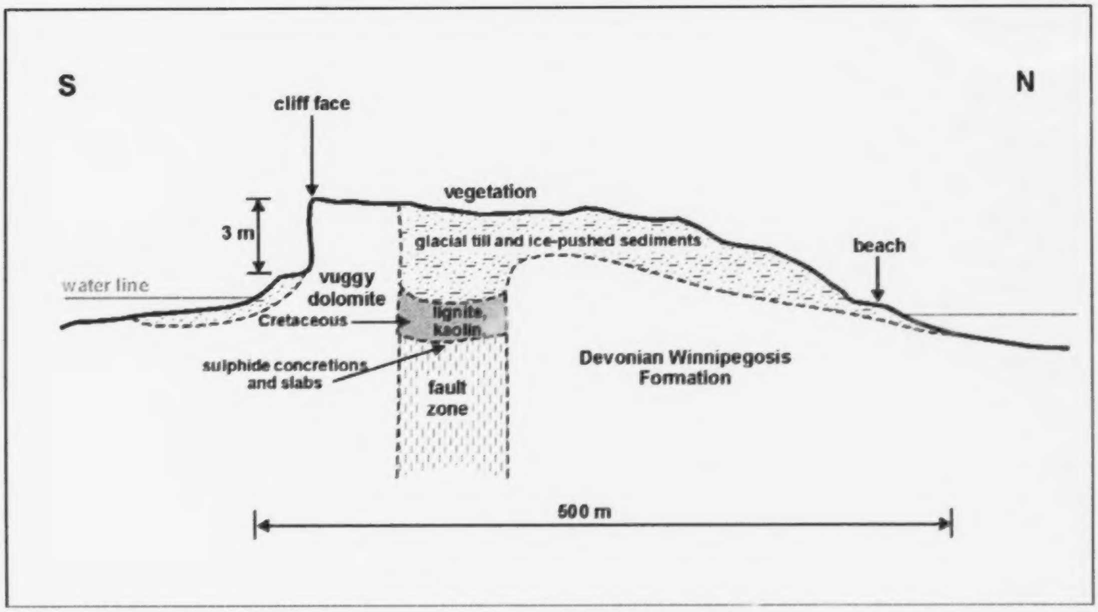

S
N
cliff face
vegetation
3 m
glacial till and ice-pushed sediments
beach
water line
vuggy dolomite
Cretaceous
lignite, kaolin
sulphide concretions and slabs
fault zone
Devonian Winnipegosis Formation
500 m

Figure GS-17-9: Composite cross-section from south to north across Pemmican Island, looking west. Line of section is shown on Figure GS-17-3. Vertical scale exaggerated about 20X.

ACKNOWLEDGMENTS

We would like to gratefully acknowledge Bonnie Lenton for preparation of the figures used in this report. Ruth Bezys is thanked for reviewing the manuscript.

REFERENCES

Baillie, A.D. 1950: Devonian geology of Lake Manitoba–Lake Winnipegosis area; Manitoba Mines and Natural Resources, Mines Branch, Publication 49-2.

Bamburak, J.D. 1999: Cretaceous black shale investigations in the northern part of the Manitoba Escarpment (parts of NTS 62J/W, 62K/N, 62N/E and 63C/W); *in* Report of Activities 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 120–122.

Bamburak, J.D., Hosain, I.T., Fedikow, M.A.F. and Dobrzanski, E. 2000: Investigations on the Camperville gravity low (parts of NTS 62N/E and 63C/E); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 202–209.

Bezys, R.K. 1996: Stratigraphic mapping (NTS 63G) and corehole drilling program 1996; *in* Report of Activities 1995, Manitoba Energy and Mines, Geological Services, p. 96–102.

Bezys, R.K., Fedikow, M.A.F. and Kjarsgaard, B.A. 1996: Evidence of Cretaceous(?) volcanism along the Churchill-Superior boundary zone, Manitoba (NTS 63G/4); *in* Report of Activities, 1996, Manitoba Energy and Mines, Geological Services, p. 122–126.

Fedikow, M.A.F., Bezys, R.K., Bamburak, J.D. and Conley, G.G. 1998: Geochemical database for Phanerozoic black shales in Manitoba; Manitoba Energy and Mines, Geological Services, Open File Report OF98-2, 123 p.

McCabe, H.R. 1978: Stratigraphic core hole and mapping programme; *in* Report of Field Activities 1978, Manitoba Mines, Resources and Environmental Management, Mineral Resources Division, p. 64–67.

McRitchie, W.D. 1991: Caves in Manitoba's Interlake region; Speleological Society of Manitoba, Winnipeg, 150 p.

McRitchie, W.D. 1995; Mineral development potential in Manitoba – nickel in the southwest extension of the Thompson Nickel Belt; Manitoba Energy and Mines, Geological Services, Economic Geology Report ER95-2, 29 p.

Norris, A.W., Uyeno, T.T. and McCabe, H.R. 1982: Devonian rocks of the Lake Winnipegosis–Lake Manitoba outcrop belt, Manitoba; Geological Survey of Canada, Memoir 392 and Manitoba Energy and Mines, Publication 77-1.

Pilkington, M. and Thomas, M.D. 2001: Magnetic and gravity maps with interpreted Precambrian basement, Manitoba; Geological Survey of Canada, Open File 3739, 4 map sheets at 1:1 500 000 scale.

Tyrrell, J.B. 1890: The Cretaceous of Manitoba; The American Journal of Science, v. XL, no. 237, p. 227–232.

Tyrrell, J.B. 1892: Report on North-Western Manitoba; *in* Annual Report of the Geological Survey of Canada (1890–91), v. V, pt. 1, p. 153E–171E.

GS-18 CHURCHILL RIVER–SOUTHERN INDIAN LAKE TARGETED GEOSCIENCE INITIATIVE (NTS 64B, 64C, 64G, 64H), MANITOBA: UPDATE AND NEW FINDINGS

by D. Corrigan[1] and N. Rayner[1]

Corrigan, D. and Rayner, N. 2002: Churchill River–Southern Indian Lake Targeted Geoscience Initiative (NTS 64B, 64C, 64G, 64H), Manitoba: update and new findings; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 144–158.

SUMMARY

This paper provides a brief summary of the fieldwork performed during the 2002 field season as part of the Churchill River–Southern Indian Lake Targeted Geoscience Initiative. This was the second of two field seasons directed at upgrading our understanding of the lithological and tectonic framework of the northern flank of the Trans-Hudson Orogen, with a main objective of providing a regional geological context to potential ore deposits. During this past field season, the transect from the central part of the Rusty Lake belt was completed southwards to the northern flank of the Burntwood Group in the Kisseynew Domain. Detailed reports and maps are pending on upcoming geochronological and geochemical analyses, and will be published within the coming months as open files.

INTRODUCTION

The Lynn Lake Multidisciplinary Geoscience Project was initiated by the Manitoba Geological Survey (MGS) in 2000 to provide an integrated and updated view on the regional geology and economic mineral potential of the Lynn Lake belt and surrounding area. In 2001 and 2002, the Geological Survey of Canada joined the MGS through a new federal government Targeted Geoscience Initiative (TGI), with the specific intention of providing a regional tectono-stratigraphic context for the Lynn Lake belt, Rusty Lake belt and other volcanic, sedimentary and plutonic belts that occur along a transect spanning the entire northern flank of the Trans-Hudson Orogen (THO), from the north flank of the Kisseynew Domain to the Wathaman-Chipewyan Batholith (Fig. GS-18-1). This TGI project covers parts of four 1:250 000-scale NTS sheets (64A, 64B, 64G, 64H) and follows up on a similar, multidisciplinary, bedrock-mapping project that was recently completed along Reindeer Lake in Saskatchewan (Corrigan et al., 1997, 1998a, 1998b, 1999a, 1999b, 2000; Corrigan, 2000a, 2000b, 2001). One of the primary goals of this TGI is to complete a similar transect

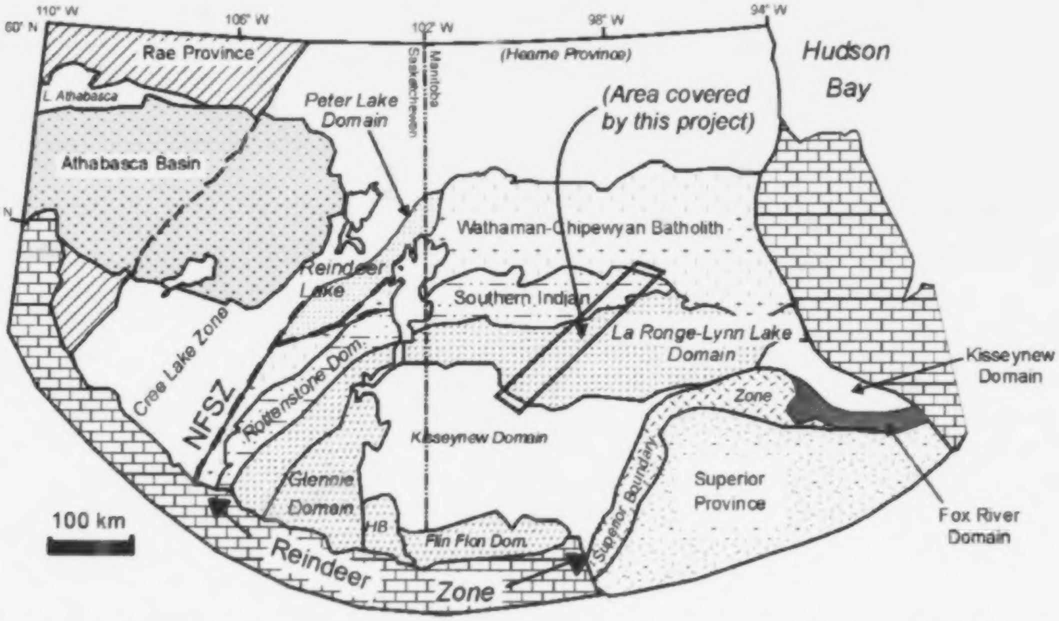

110° W
106° W
102° W
98° W
94° W
60° N
58° N
Rae Province
(Hearne Province)
Hudson Bay
L. Athabasca
Peter Lake Domain
Manitoba
Saskatchewan
(Area covered by this project)
Athabasca Basin
Wathaman-Chipewyan Batholith
Reindeer Lake
Southern Indian
La Ronge-Lynn Lake Domain
Cree Lake Zone
NFSZ
Rottenstone Dom.
Kisseynew Domain
Zone
Kisseynew Domain
Glennie Domain
HB
Flin Flon Dom.
Superior Boundary
Superior Province
Fox River Domain
100 km
Reindeer Zone

Figure GS-18-1: Simplified geology of the Trans-Hudson Orogen in Manitoba and Saskatchewan (after Lewry and Collerson, 1990). Abbreviation: NFSZ, Needle Falls Shear Zone.

---

[1] Geological Survey of Canada, 615 Booth Street, Ottawa, Ontario K1A 0E9

from the northern flank of the Kisseynew Domain to the southern margin of the Wathaman-Chipewyan Batholith (Fig. GS-18-2). The new data will enable a better understand of the tectonostratigraphic framework and tectonic evolution of the Lynn Lake and associated belts in northern Manitoba. Integration of the results with those from the Reindeer Lake transect will further the understanding of the Trans-Hudson Orogen, provide a tectonic context for ore formation and mineralization, and permit comparisons with other known metallotects (e.g., the Flin Flon and Snow Lake belts).

Results presented herein highlight preliminary findings of the second of two field seasons. Emphasis during the 2002 field season was not directed at systematic bedrock remapping, since that had been previously done in relative detail, but at the re-evaluation of lithological assemblages in terms of protolith origin, geochemical signature, isotopic age, tectonic environment of emplacement/deposition, and provenance (in the case of major sedimentary units). The GSC-led regional synthesis 'dovetails' with detailed structural, geochronological and metallogenic studies of the Lynn Lake belt undertaken by the Manitoba Geological Survey (Beaumont-Smith and Böhm, GS-19, this volume) in collaboration with the Universities of Alberta and New Brunswick, and Laurentian University. In the first summer, the work covered, at various scales, an area of approximately 8000 km^2, extending from the Rusty Lake belt at the latitude of Leaf Rapids to the Partridge Breast Lake Belt on the lower Churchill River. Fieldwork consisted mainly of traverses by boat and on foot on the shoreline and islands of the better exposed Churchill River–Southern Indian Lake system, as well as a transect, mainly by road access, across the northwestern portion of the Rusty Lake belt. Preliminary results were summarized in Corrigan et al. (2001). This summer saw the completion of the southern half of the regional transect, from Leaf Rapids to Wheatcroft Lake, south of Granville Lake. The main points of this past field season are summarized below. A brief, partial summary of the preliminary radiogenic isotope data and their first-order implications is also provided.

REGIONAL GEOLOGY

The supracrustal and associated plutonic rocks on the northern flank of the THO in Manitoba have been previously assigned to three main lithological packages: the Kisseynew, Lynn Lake–Leaf Rapids and Southern Indian domains.

The Kisseynew Domain comprises mainly upper amphibolite to granulite facies metaturbidite of the Burntwood Group, flanked to the north by fluvial to shallow marine meta-arkosic and psammitic rocks of the Sickle Group.

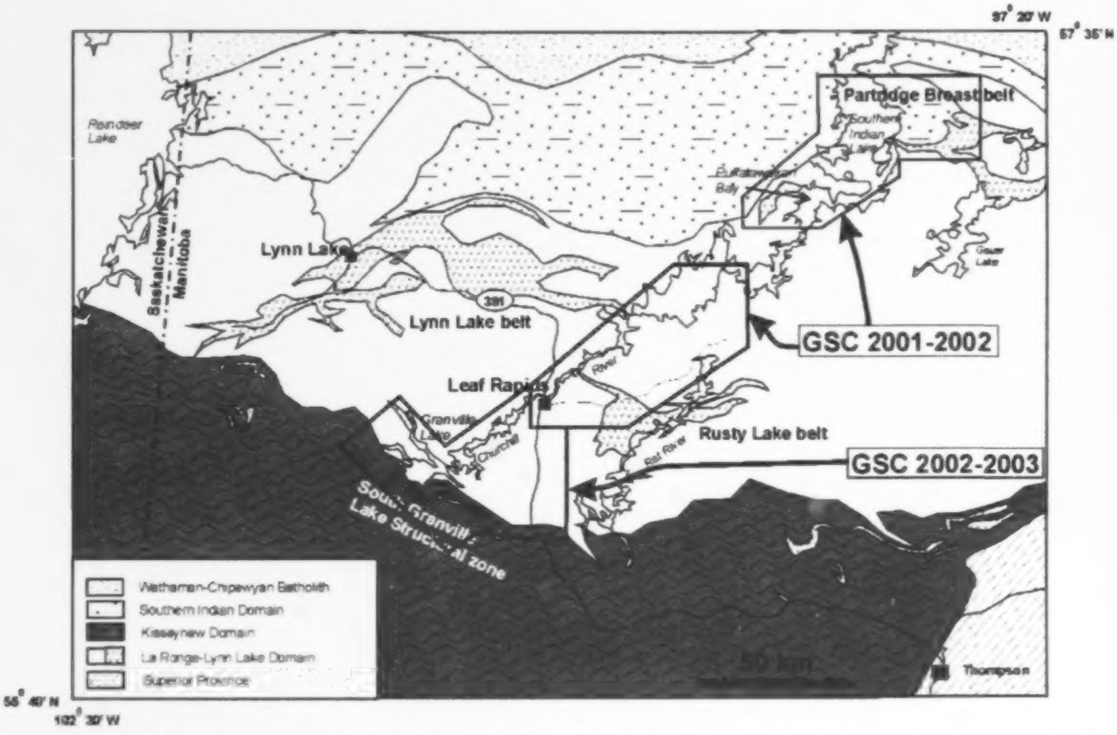

97° 20' W
57° 35' N
Partridge Breast belt
Southern Indian Lake
Reindeer Lake
Bay
Saskatchewan
Manitoba
Lynn Lake
Gauer Lake
391
Lynn Lake belt
GSC 2001-2002
Leaf Rapids
River
Granville Lake
Churchill
Rusty Lake belt
Rat River
GSC 2002-2003
South Granville Lake Structural zone
Wathaman-Chipewyan Batholith
Southern Indian Domain
Kisseynew Domain
La Ronge-Lynn Lake Domain
Superior Province
50 km
Thompson
55° 45' N
102° 30' W

Figure GS-18-2: Major geological domains along the north flank of the Trans-Hudson Orogen in Manitoba, showing approximate areas covered by this project.

Geochronological data obtained mainly on the southern and western margins of the Kisseynew Domain constrain the ages of deposition during the interval 1.85–1.84 Ga for the Burntwood Group and 1.84–1.835 Ga for the Sickle Group (Ansdell and Yang, 1995). The structural boundary between the Burntwood and Sickle groups is also the site of a narrow but laterally continuous unit (over 400 km in strike length) that comprises folded and boudinaged mafic flows and sills of mid-ocean ridge basalt (MORB) affinity, interlayered with calcareous psammite, metapelite and minor quartzite. This package, named the Levesque Bay assemblage in Saskatchewan (Corrigan et al., 1998b, 1999b) is intruded by 1896 +18/–16 Ma leucogranite dikes, suggesting that it may be either contemporaneous with, or older than, the La Ronge and Lynn Lake arcs. The Levesque Bay assemblage stratigraphically correlates with the MacLean Lake belt in Saskatchewan (Thomas, 1993; Harper, 1998) and the Granville Lake structural zone in Manitoba (Zwanzig, 2000).

The Kisseynew Domain is flanked to the north by the Lynn Lake–Leaf Rapids Domain, which comprises a tectonic collage of ca. 1.90–1.88 Ga (Baldwin et al., 1987) volcanic and associated epiclastic and sedimentary rocks (*see*, however, Beaumont-Smith and Böhm, GS-19, this volume). Most of the tectonostratigraphic elements can be correlated with units in the La Ronge Domain in Saskatchewan (Maxeiner et al., 2001). Two major volcanic belts have been identified, the Lynn Lake and Rusty Lake belts, each of which has been further subdivided into separate lithotectonic components and subcomponents based on geochemical signature and inferred plate-tectonic setting, which includes tholeiitic arc, calc-alkaline arc, MORB-like and oceanic island basalt (OIB)–like rocks (Syme, 1985; Ames and Taylor, 1996; Zwanzig et al., 1999). Field relationships suggest that the various volcano-sedimentary assemblages were aggregated into a tectonic collage before the emplacement of calc-alkaline plutons, which include ca. 1876 Ma gabbro stocks and tonalite (Baldwin et al., 1987).

The Southern Indian Domain flanks the Lynn Lake–Rusty Lake belt to the north and, for the most part, correlates with the Rottenstone Domain in Saskatchewan. It is dominated by foliated granitoid orthogneiss and clastic sedimentary rocks that include conglomerate, greywacke and metaturbidite, as well as subordinate rocks of volcanic origin. Recent work on Reindeer Lake in Saskatchewan has led to the recognition of at least two distinct sedimentary basins in the Rottenstone Domain. They consist of the Milton Island assemblage (Corrigan et al., 1997), interpreted as a fore-arc or accretionary complex formed north of the advancing La Ronge–Lynn Lake arc, and the Park Island assemblage (Corrigan et al., 1999b), interpreted as forming part of a foreland–molasse basin that was deposited on the Hearne continental margin and its autochthonous cover sequence as a result of tectonic loading of the La Ronge–Lynn Lake arc. Stratigraphic equivalents of the Park Island assemblage have also been interpreted to occur in the upper sequence of the Wollaston Domain (Janice Lake assemblage; Yeo, 1998).

The area north and south of the Southern Indian Domain is dominated by the voluminous Chipewyan Batholith and related Baldock and Livingston plutons. The Chipewyan Batholith is the Manitoba equivalent of the Wathaman Batholith and consists of a continental magmatic arc that was emplaced during the interval 1.86–1.85 Ga (Fumerton et al., 1984; Van Schmus and Schledewitz, 1986; Meyer et al., 1992). Compositions within the batholith range mainly from quartz diorite to syenogranite, with hornblende-biotite monzogranite forming the most abundant rock type. The ca. 1855 Ma Baldock granite (Van Schmus; U-Pb zircon age cited in Manitoba Energy and Mines, 1990) intrudes supracrustal rocks and orthogneiss of the Southern Indian Domain along its northern margin and appears to merge with the Wathaman-Chipewyan Batholith east of the Partridge Breast Lake belt. It intrudes supracrustal and plutonic rocks of the Rusty Lake belt on its southern flank. The Livingston granodiorite forms another east-trending elongate pluton that intrudes the Rusty Lake belt on its northern margin and the Sickle and Burntwood groups along its southern margin. Its emplacement age is presently unconstrained.

GRANVILLE LAKE–CHURCHILL RIVER AREA

Mapping during the 2002 field season was concentrated on the Granville Lake area of the Churchill River system (Fig. GS-18-3), completing the regional transect across the northern flank of the Trans-Hudson Orogen, from the northern flank of the Kisseynew Domain to the Wathaman-Chipewyan Batholith. The objective of this second and last season of field mapping was mainly to investigate the tectonostratigraphy of the northern Kisseynew Domain, in light of new constraints established from a similar transect in Saskatchewan (Corrigan et al., 1999a, 2000b), which suggested the presence of potentially older supracrustal rocks (the ca. 1.89 Ga Levesque Bay assemblage), tectonically imbricated between the ca. 1.85–1.84 Ga Burntwood and Sickle groups.

The Granville Lake area was mapped by Barry (1965), Barry and Gait (1966), Cranstone (1968), Campbell and Kendrick (1972) and Zwanzig (1981), with a reissued map by Zwanzig and Cameron (2002). Along Churchill River, Laurie River and Granville Lake, the Burntwood and Sickle groups are relatively well exposed, forming a predominantly south-dipping stack of variably strained, lower- to middle-amphibolite facies siliciclastic rocks with minor

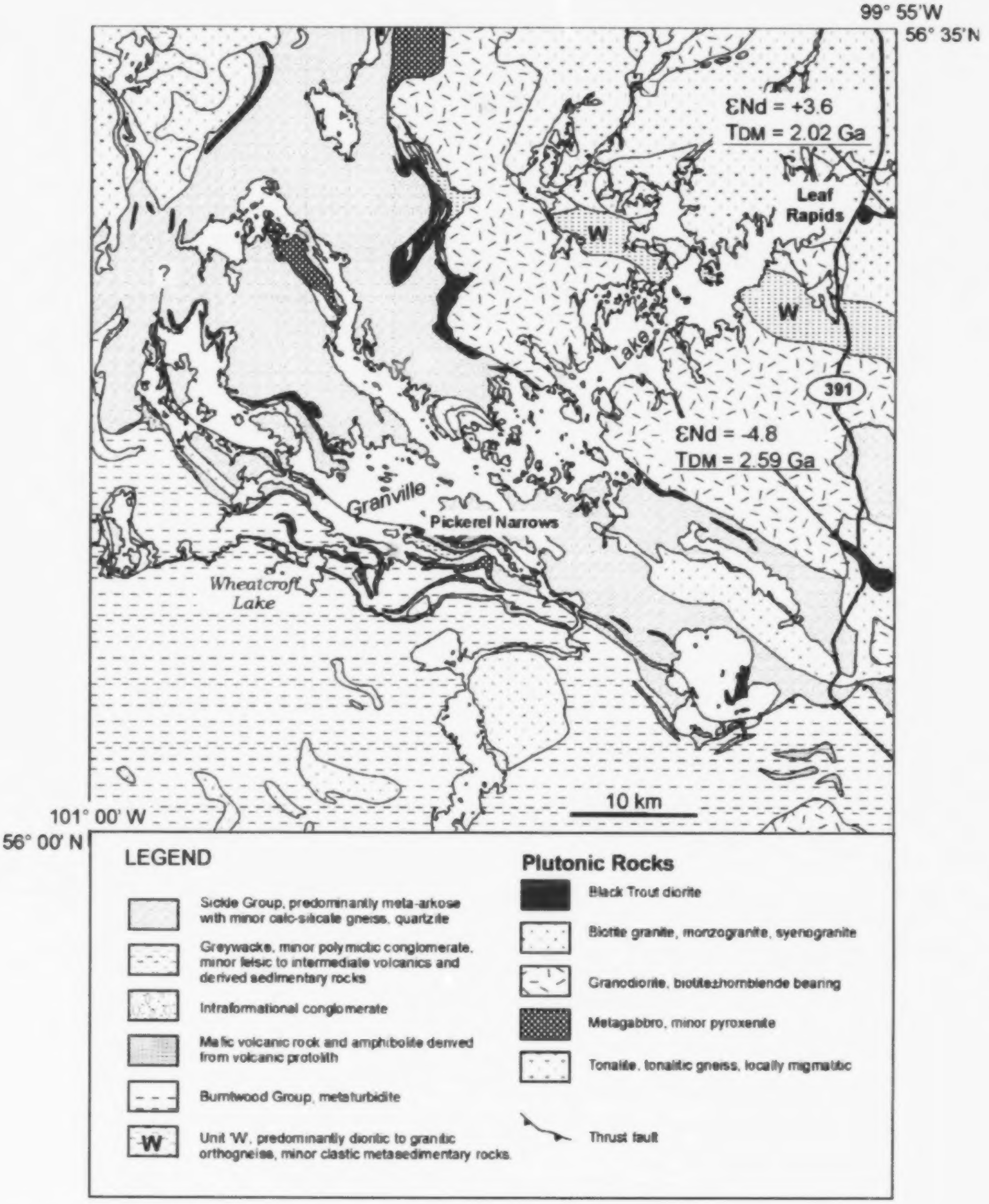

99° 55'W
56° 35'N
εNd = +3.6
TDM = 2.02 Ga
Leaf Rapids
W
W
Lake
391
?
εNd = -4.8
TDM = 2.59 Ga
Granville
Pickerel Narrows
Wheatcroft Lake
10 km
101° 00' W
56° 00' N
LEGEND
Sickle Group, predominantly meta-arkose with minor calc-silicate gneiss, quartzite
Greywacke, minor polymictic conglomerate, minor felsic to intermediate volcanics and derived sedimentary rocks
Intraformational conglomerate
Mafic volcanic rock and amphibolite derived from volcanic protolith
Burntwood Group, metaturbidite
W
Unit 'W', predominantly dioritic to granitic orthogneiss, minor clastic metasedimentary rocks
Plutonic Rocks
Black Trout diorite
Biotite granite, monzogranite, syenogranite
Granodiorite, biotite±hornblende bearing
Metagabbro, minor pyroxenite
Tonalite, tonalitic gneiss, locally migmatitic
Thrust fault

Figure GS-18-3: Simplified geology of the Granville Lake area (after Manitoba Energy and Mines, 1986a, b).

volcanic flows and sills. Mafic volcanic flows are concentrated in the upper stratigraphic levels of the Burntwood Group, as well as in an approximately 2 km wide band lying between the Burntwood and Sickle groups, informally named the 'Granville Lake structural zone' (Zwanzig, 1990). The Sickle Group forms an upright syncline with its southern limb in structural contact with the Burntwood Group and its northern limb in possible unconformable contact with underlying granitoid rocks (*see* below). The above are intruded by more than one suite of mafic to felsic plutons and sills, as is suggested from relationships with the various sedimentary sequences and structures. The following sections provide brief descriptions of the tectonostratigraphy of the Burntwood and Sickle groups.

Burntwood Group

In the Wheatcroft Lake area south of Granville Lake, the Burntwood Group is affected by a regional metamorphic low, with mineral assemblages suggesting middle to lower amphibolite facies. Sedimentary structures, although substantially shortened perpendicular to bedding, are well preserved and suggestive of deposition by turbidity currents in a deep basin. Bedding couplets, ranging from a few millimetres to a few tens of centimetres thick and grading from psammite to psammopelite and more rarely to pelite, form the dominant sedimentary facies (Fig. GS-18-4). Although massive to laminar beds account for most of the structures observed, crossbeds are present but less common. Oval-shaped, calc-silicate pods, up to one metre in long axis length, are common throughout the siliciclastic rocks. They likely represent metamorphosed calc-silicate nodules. Younging directions are common and suggest that the entire sequence is overturned to the north, with minor facing reversals on short limbs of asymmetric folds. The metamorphic assemblage in the pelitic layers is biotite-garnet-sillimanite±cordierite±staurolite.

The structurally lowest — and stratigraphically highest — part of the Burntwood Group contains concordant amphibolite layers, up to 250 m thick and continuous over a strike distance of tens of kilometres or more. Of those observed this summer, only two appeared to be unequivocally derived from a volcanic protolith, with an overall very fine grained texture, abundant calc-silicate alteration and preservation of pillow rinds. The majority are medium to coarse grained, more compositionally and texturally homogeneous, and contain chilled margins, suggesting that they were derived from a mafic intrusive protolith of apparently gabbroic to dioritic composition.

Granville Lake structural zone

This south-dipping supracrustal assemblage sits structurally beneath Burntwood Group metaturbidite. It contains numerous north-younging (overturned) top indicators with rare south-facing ones, suggesting that it stratigraphically overlies Burntwood Group turbidite and contains a similar style of folds. It is compositionally heterogeneous, containing coarse- to fine-grained siliciclastic rocks, calc-silicate gneiss and greywacke, as well as mafic to intermediate volcanic and associated volcaniclastic rocks. Its stratigraphic base consists of a finely laminated psammite that grades rapidly into a quasi-monolithic (intraformational), grey, clast-supported conglomerate (Fig. GS-18-5) with distinctive pebble- to cobble-sized clasts that strongly resemble the psammitic layers within the Burntwood turbidite. Most of the clasts are massive, but some contain laminar and crossbedded structures, as well as graded beds typical of some of the horizons found in the turbidite. The conglomerate also contains rare calc-silicate clasts, possibly derived from the carbonate concretions described above. This nearly monolithic, potentially locally derived clast composition is quite distinctive from the usually polymictic, granitoid-rich nature documented elsewhere for the base of the Sickle Group and its Saskatchewan equivalent (McLellan Group).

The conglomerate grades upwards into grey to pink, amphibole-bearing meta-arkose (Fig. GS-18-6), which grades into a pink to light grey, biotite- and muscovite-rich, magnetite-bearing, locally crossbedded arkose that is, in many aspects, indistinguishable from 'proper' Sickle arkose. This arkose-dominated layer, a few hundreds of metres wide, is in turn overlain by relatively thin and laterally discontinuous horizons of mafic tuff (or mafic wacke), greywacke and polymictic conglomerate, with thin, minor marble and impure quartzite horizons. The mafic tuff-wacke contains rounded

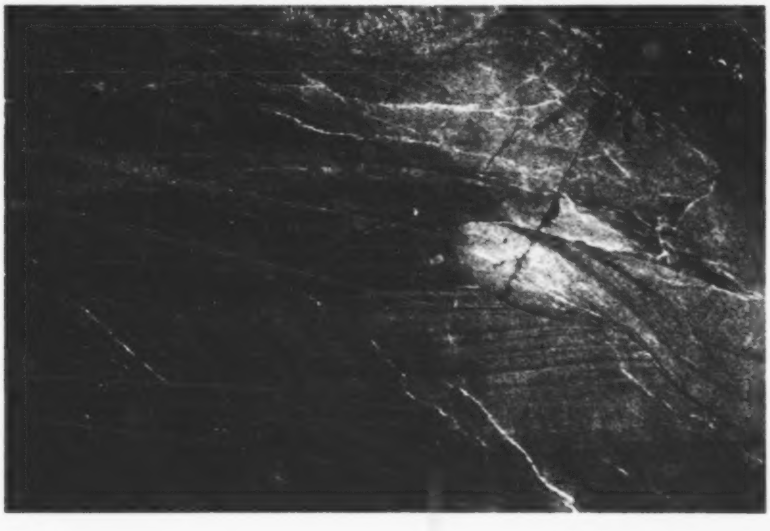


Figure GS-18-4: Burntwood Group turbidite showing graded psammite beds and calc-silicate concretions (arrow), south shore of Granville Lake. Pencil for scale.

Figure GS-18-5: Intraformational, clast-supported conglomerate with psammite cobbles. Note crossbeds in the large clast in centre of photograph. Coin is 2.8 cm in diameter.

Figure GS-18-6: Bedded, hornblende- and biotite–bearing, 'Sickle-like' meta-arkose from the Granville Lake structural zone, southern shore of Granville Lake. Note large hornblende porphyroblasts in the layer in centre of photograph. A similar unit has been observed in the >1.86 Ga Park Island assemblage along Reindeer Lake in Saskatchewan. Coin is 2.8 cm in diameter.

to subangular mafic fragments set in a mafic to intermediate matrix (hornblende-biotite-plagioclase-quartz). It is massive to well banded and contains rare, grey, aphanitic quartzite layers that may represent recrystallized chert horizons. In the western Granville Lake area, the mafic tuff-wacke locally grades stratigraphically upwards into a well-banded greywacke a few tens of metres thick, which is in turn overlain by a thick mafic volcanic flow. In the Pickerel narrows[2] area, the transition from 'Sickle-like' meta-arkose to the upper mafic volcanic flow is more complex.

A section through the well-exposed shoreline near this locality shows a transition, moving stratigraphically upwards, from mainly biotite psammite to a felsic fragmental rock with a fine-grained, bone white matrix, interpreted as a rhyodacitic to dacitic tuff (Fig. GS-18-7), that in turn grades upwards into rhyolite. This layer is overlain by a hornblende- and biotite-bearing greywacke a few tens of metres thick, which grades stratigraphically upwards into psammopelite with abundant faserkiesel (Fig. GS-18-8). The psammopelite is overlain by polymictic conglomerate along a relatively sharp conformable contact (Fig. GS-18-9). Clasts are angular to rounded and are predominantly derived from mafic to felsic volcanic rocks, but include siliciclastic sedimentary rocks as well as fine-grained felsic granitoid bodies. The polymictic conglomerate grades stratigraphically upwards into grey psammite, which is itself overlain by calc-silicate rock and by a thick, highly altered mafic volcanic horizon. A third section along the upper Churchill River, east of Pickerel narrows, highlighted a more complex stratigraphy than the ones described above, with the presence of numerous, relatively thin layers of quartzite (?metachert), ultramafic flows or sills, and mafic wacke interlayers within the mafic volcanic flows. In contrast with the sections to the west, the mafic flows along this section rest directly on 'Sickle-like' meta-arkosic rocks.

---

[2] unofficial name

An immediate question that comes to mind regarding the Granville Lake structural zone is whether the intraformational conglomerate located at the base of the sequence, as well as the 'Sickle-like' meta-arkose lying stratigraphically above, belong to the Sickle Group in the strict sense, or whether they form a distinct package integral to the Granville Lake structural zone. This distinction has important tectonic and stratigraphic implications and needs serious consideration. A similar conundrum resulted from mapping a detailed section through the Levesque Bay assemblage along Reindeer Lake, Saskatchewan, where meta-arkose previously assumed to belong to the McLennan (i.e., Sickle) Group were found to be intruded by 1867 ± 4 Ma tonalite, which provided a minimum age of deposition for that unit. This contrasts sharply with the presently established age of ca 1840–1835 Ma for deposition of the McLennan Group arkose (Ansdell and Yang, 1995) and the Missi Group in the Flin Flon area, which is believed to be a Sickle equivalent (Stauffer, 1990).

Figure GS-18-7: Felsic tuff-breccia with fragments of intermediate composition, shore of island west of the community of Pickerel narrows. Coin is 2.8 cm in diameter.

Sickle Group

A large proportion of the Sickle Group occurs in the Granville Lake area and forms large, kilometre-scale, gently plunging, upright folds. The basal unit, exposed along both southern and northern flanks of the fold structure, consists of a muscovite-bearing impure quartzite a few decimetres to a few tens of metres thick (Fig. GS-18-10). Along the southern flank, it is strongly mylonitized and forms the footwall of a north-verging thrust fault (Fig. GS-18-11), with mafic volcanic rocks of the Granville Lake assemblage forming the hanging wall. Along the northern flank of the fold structure, the basal quartzite is in contact with a large, variably foliated, biotite granite (Fig. GS-18-12) that shows a strain increase towards the contact with the quartzite.

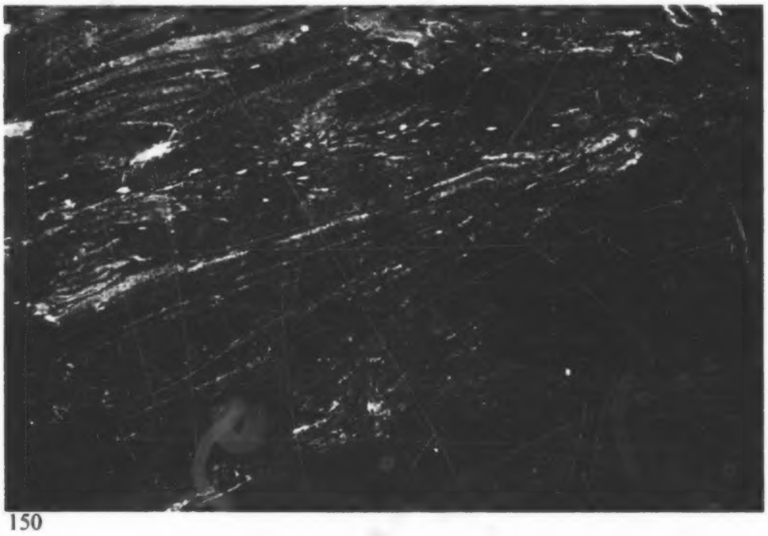


Figure GS-18-8: Metapelitic rock from the Granville Lake structural zone, southern shore of Granville Lake, showing faserkiesel (fibrolite knots) oriented at a slight anticlockwise angle to the transposed beds. Pen for scale.

Figure GS-18-9: Polymictic conglomerate from the Granville Lake structural zone, southern shore of Granville Lake. Note the subangular to subrounded shape of the clasts, suggesting a relatively proximal source. Coin is 2.8 cm in diameter.

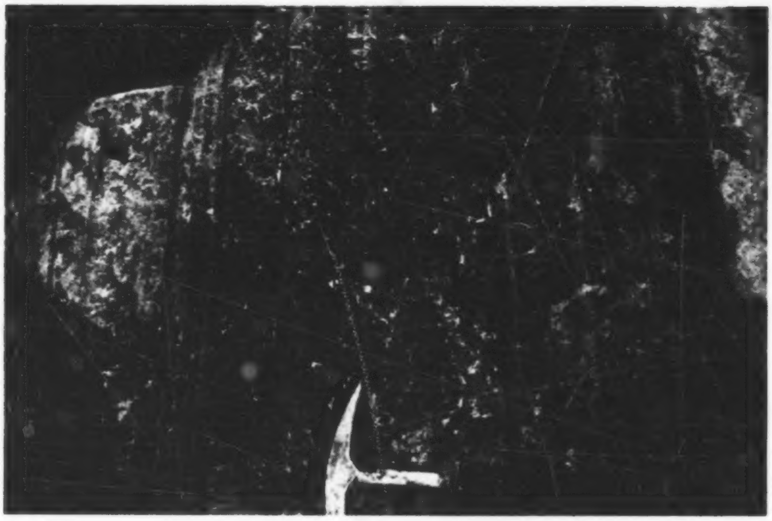
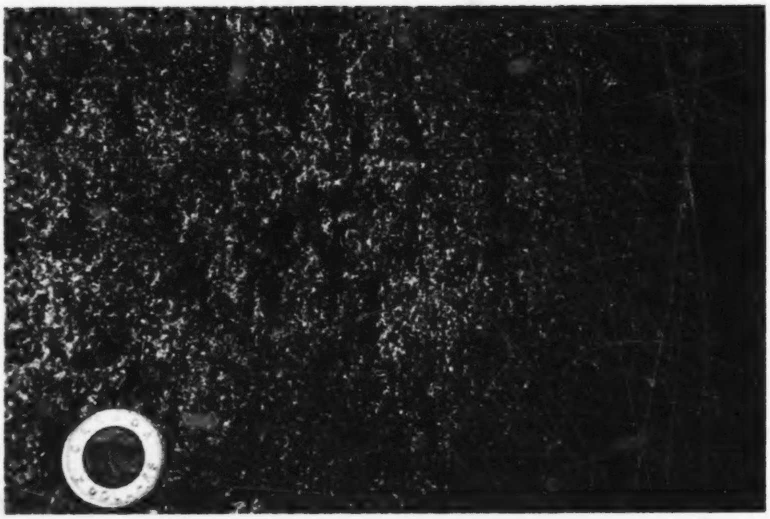


Figure GS-18-10: Steeply dipping quartzitic base of the Sickle Group, along its northern flank on Granville Lake. Dark grey bands are nearly pure quartzite; lighter coloured and narrower bands are muscovite rich.

Figure GS-18-11: Highly strained and flaggy quartzite from the stratigraphic base of the Sickle Group on Granville Lake. View is to the west, and shows the moderate southerly dip surface. Mylonitic mafic volcanic rocks from the leading edge of the Granville Lake structural zone are to the left of the picture (not shown). Stretching lineation is nearly down-dip (not shown). Person for scale.

Figure GS-18-12: Coarse-grained monzogranite flanking the Sickle Group to the north, along Granville Lake. The moderate foliation fabric (top to bottom on photograph) is parallel to the transposition plane in the adjacent quartzite. Fibrolite-muscovite–rich knots (arrow) are only present in the monzogranite near the contact with the quartzite. Coin is 2.8 cm in diameter.



The quartzite contains variable muscovite concentrations and locally includes rare, quartz pebble conglomerate lenses. The biotite granite contains an increasing abundance of muscovite towards the contact with the quartzite. Foliation is parallel in both units, and parallel to the contact. The presence (although rare) of pebble conglomerate in the quartzite, the absence of quartzite xenoliths in the granite, and the high concentration of muscovite in the granite margin all suggest that this may be a reworked unconformity. However, the possibility that it is a reworked intrusive contact cannot be ruled out. In order to address this question, a sample of the quartzite was taken for U-Pb sensitive high-resolution ion microprobe (SHRIMP) analysis, and a sample of the biotite granite was taken for U-Pb thermal ionization mass spectrometry (TIMS) analysis. If the biotite granite is indeed basement to the quartzite, its emplacement age should be older than the youngest detrital zircon grain in the quartzite. A granite intruding the Sickle Group was also sampled in order to provide constraints on the minimum age of the latter.

Supracrustal rocks north of the Sickle Group (unit 'W')

North of the Sickle Group in the Leaf Rapids Domain, a major linear belt had been previously interpreted as a predominantly supracrustal unit of unknown age (unit 'W' in Manitoba Energy and Mines, 1986a). This belt was revisited in order to determine its age and relationship relative to other supracrustal belts in the immediate region. A detailed transect through the well-exposed shoreline and islands along Granville Lake indicated that rocks of sedimentary or volcanic origin form only a very limited portion of this unit, with most of the belt being composed of banded gneiss of definite plutonic origin. The metasedimentary rocks, which form either transposed enclaves in the metaplutonic rocks or elongate subunits a few metres to a few hundred metres thick, are predominantly composed of biotite-muscovite-sillimanite–bearing psammite and psammopelite. One single unit of potential — but equivocal — volcanic origin was observed. It consists of a 3 m thick layer of banded mafic to ultramafic rock with carbonate alteration, and is associated with a rusty, mafic to intermediate gneiss of probable volcaniclastic origin. Overall, unit 'W' is mainly composed of moderately to highly strained banded orthogneiss of granitic to ultramafic composition. Within a few tens of metres, one can walk on continuously exposed bedrock from what is clearly an intrusive complex (Fig. GS-18-13), with multiple injections of variable composition, to an essentially 'straight' banded gneiss that strongly resembles a volcanic-derived sediment (Fig. GS-18-14, GS-18-15).

Plutons and sills in the Granville Lake area

Field relationships and preliminary Sm-Nd data suggest that there are at least three generations of plutonic rock suites in the north flank of Kisseynew Domain and southwestern Rusty Lake belt, within the Granville Lake area. The potentially oldest suite is located in the Rusty Lake belt, approximately 20 km south of Leaf Rapids, and consists of a migmatitic granitic gneiss (Fig. GS-18-16) intruded by a foliated diorite, which yielded a T_{dm} Nd model age of 2.83 Ga and an ε_{Nd} value of –7.1 (Ch.O. Böhm and R. Creaser, pers. comm., 2002), indicating either that it is an Archean to early Paleoproterozoic rock, or that it is Proterozoic but has incorporated a substantial amount of Archean crust during its generation and emplacement. However, this Nd model age is consistent with another, similar Nd model age obtained on a tonalite from the Southern Indian Domain, which yielded a U-Pb zircon age of ca. 2.45 Ga (N. Rayner,

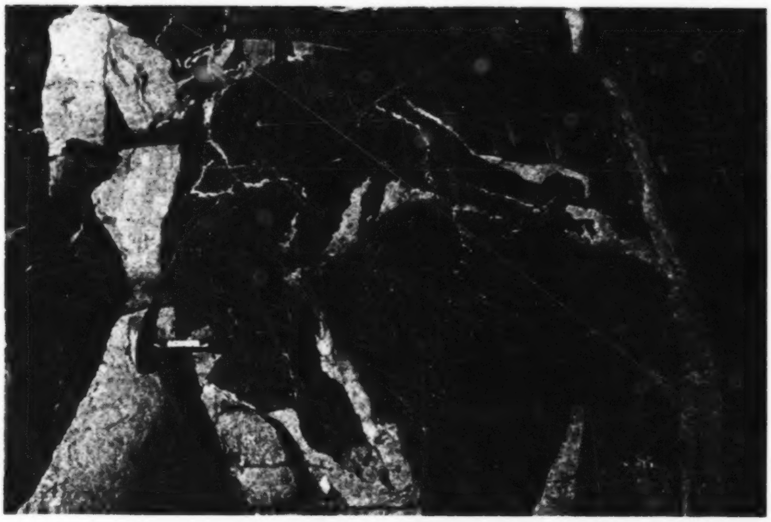


Figure GS-18-13: Banded tonalite (bottom right) intruded by diorite (black with white specks and syenogranite (light coloured dikes and veins).

unpublished preliminary data, 2002). A U-Pb SHRIMP study is currently underway to verify this preliminary model age. These new data suggest that there are likely crustal-scale slivers of Neoarchean to earliest Paleoproterozoic age tectonically imbricated with juvenile rocks of the Lynn Lake–Rusty Lake belt and Southern Indian Domain.

All plutonic rocks described in the previous paragraph are completely recrystallized and do not retain original igneous textures or minerals. However, potentially younger suite(s), including large gabbroic to granitic plutons, are intrusive into the supracrustal rocks of the northern margin of the Kisseynew Domain and the Rusty Lake belt. These are generally larger in size, more compositionally homogeneous and, in most cases (at least locally), preserve relict igneous textures and minerals (Fig. GS-18-17). They range in size from a few kilometres to a few tens of kilometres, and in composition from gabbroic to syenogranitic. In the Granville Lake area, they include the Black Trout diorite (Fig. GS-18-18) and elongate gabbroic to granitic sheets. During the course of the fieldwork, all plutonic rocks observed along a transect from Wheatcroft lake to Outlaw Bay were systematically sampled for geochemical analysis, and most of the representative suites were sampled for Sm-Nd tracer isotope analysis. Six were sampled for U-Pb isotopic dating, including the Black Trout diorite. Results will be published in a subsequent report.

Locally, the Black Trout diorite contains immiscible magmas of mafic (amphibolite) and felsic (granitic) composition; when transposed, these form a characteristic banded gneiss. An identical intrusion was observed in the Pukatawakan belt, approximately 100 km to the north (*see* Corrigan et al., 2001), and yielded a positive ε_{Nd} value and a Proterozoic (ca. 2.38 Ga) Nd model age (Ch.O. Böhm and R. Creaser, pers. comm., 2002).

Figure GS-18-14: Same outcrop as Figure GS-18-12, showing moderate transposition of the intrusive layers into parallelism with the regional structural grain.

UPDATE ON U-PB, SM-ND AND GEOCHEMICAL WORK

During the 2001 field season, 12 samples were taken along a transect from the Rusty Lake belt to the Wathaman-Chipewyan Batholith, in order to constrain the emplacement age of plutonic and volcanic rocks, as well as the depositional age and source of sediments in the Rusty Lake belt and Southern Indian Domain. In addition, 24 rocks were analyzed for Sm-Nd systematics and over 100 rocks were analyzed for major element, trace element and rare earth element geochemistry. During the 2002 field season, a similar number of samples was taken from representative rock units extending from the north flank of the Kisseynew Domain to the Rusty Lake belt. The combined dataset will provide constraints on the lithological framework and tectonic evolution of the northern flank of the Trans-Hudson Orogen, from the Kisseynew Domain to the Wathaman-Chipewyan Batholith. In particular, it will provide a context for comparing and contrasting the nature, evolution and mineral potential of the Lynn Lake and Rusty Lake belts, as well as smaller, isolated supracrustal belts in the Kisseynew and Southern Indian domains. A thorough description of the results obtained to date is beyond the scope of this preliminary report of current activities, and will be presented in an open file report (D. Corrigan, work in progress, 2002). To date, the preliminary radiogenic isotope data indicate the following:

- Sediments derived from erosion of Rusty Lake belt volcanic rocks contain zircons that range in age from ca. 1.92 to 1.88 Ga, reflecting the approximate age range of the source plutonic and volcanic rocks within the belt. These data are compatible with detritus ages from sedimentary rocks associated with the La Ronge belt in Saskatchewan (D. Corrigan, work in progress, 2002), indicating a similar age range for the two belts.

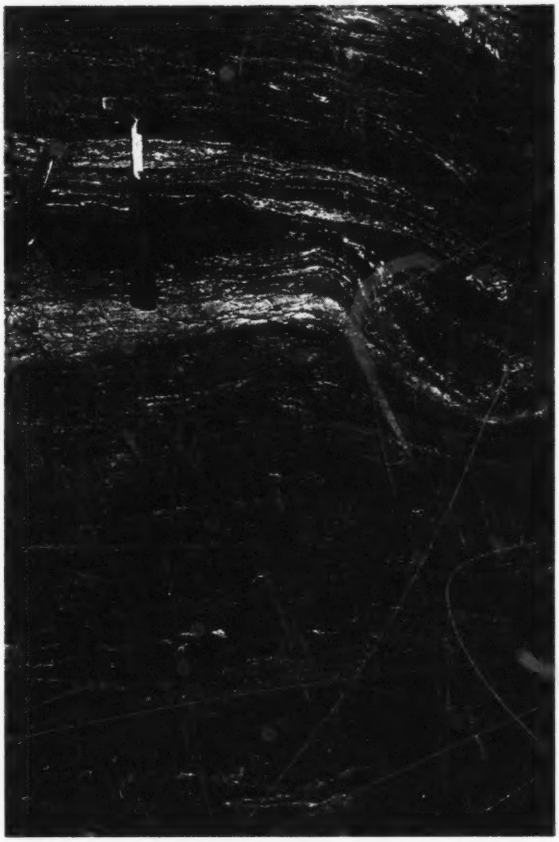


Figure GS-18-15: Same outcrop as Figure GS-18-14, showing a more complete stage of recrystallization and transposition of plutonic protoliths, into a well-banded orthogneiss.

- A porphyry rhyolite from the upper stratigraphic levels of the western domain of the Rusty Lake belt yielded a ca. 1884 Ma age, constraining the minimum age of volcanism in the Ruttan mine sequence to approximately that age. The previous interpretation of ca. 1878 Ma for the Rusty Lake belt (Baldwin et al., 1987) hinged on a single U-Pb age from the Karsakuwigamak block and likely reflected late caldera formation.
- A significant portion of the Southern Indian Domain may be underlain by Archean crust intruded by ca. 2.45 Ga (Rayner et al., work in progress, 2002), mixed to layered plutons of ultramafic to intermediate composition, including the Turtle Island intrusive complex (Corrigan et al., 2001). Preliminary Sm-Nd data suggest that a small (?)tectonic sliver of Archean crust may also be present in the Rusty Lake belt, south of the Ruttan mine.
- Polymictic conglomerate and meta-arkose in the Southern Indian Domain, previously interpreted as 'Sickle-like' (Cranstone, 1972), yielded detrital zircons of ca. 1.88 Ga to Neoarchean age, suggesting a likely source from the Lynn Lake and Rusty Lake belts, including minor components of earliest Proterozoic to Neoarchean source rocks. A similar rock assemblage located at a similar tectonostratigraphic level was identified and dated in Saskatchewan (Park Island assemblage; Corrigan et al., 1999a) and tentatively interpreted as a foredeep or molasse basin deposited on the continent side of an early, accreted, oceanic-arc assemblage (La Ronge–Lynn Lake–Rusty Lake belts).
- Potassium feldspar megacrystic granite, similar in every aspect to the 1.86 to 1.85 Ga Wathaman-Chipewyan Batholith, yielded a ca. 1.83 Ga age, suggesting that either 1) the age range of the Wathaman-Chipewyan Batholith is broader than previously accepted, or 2) a separate event occurred at ca. 1.83 Ga and produced magmas similar in composition to the Wathaman-Chipewyan Batholith.

ECONOMIC POTENTIAL

Granville and Wheatcroft lakes sit on one of the largest Cu-Au and As lake-sediment anomalies in northern Manitoba (Kaszycki et al., 1988). Apart from minor sulphide mineralization associated with the mafic volcanic layer on Wheatcroft Lake, no major gossan zones or alteration zones were observed along the exposed bedrock. This suggests that, if a major mineralized zone exists in the region, it is likely buried under glacial drift. However, very minor Cu mineralization was observed in association with pegmatite bodies at the margin of a large gabbroic intrusion in the Sickle Group. There may also be potential for shear zone–hosted Au mineralization along the leading edge of the Granville Lake structural zone, at the interface between the hanging wall mafic volcanic rocks and the footwall quartzite. Tourmaline±garnet±beryl–bearing pegmatite bodies, injected in the Sickle Group in the aureole of granitic plutons, may also present potential targets for rare earth element mineralization.

In the 2001 field season, one grab sample of tourmaline-garnet pegmatite from the Partridge Breast Lake belt, from an outcrop on the shore of the lower Churchill River near Partridge Breast Lake, returned interesting Nb (57 ppm) and Ta (27 ppm) values. The analysis also revealed significant values of Be, indicating the likely presence of beryl in the sample. This type of pegmatite may be related to the fluorine-bearing Thorsteinson granite (T. Corkery, pers. comm., 2001), located approximately 15 km southeast of the sampled pegmatite.

In terms of gold exploration, the Rusty Lake belt remains relatively poorly explored, despite high potential indicated by the presence of late shear zones in volcanic rock (an environment similar to that of known gold occurrences in the Lynn Lake belt), as well as the presence of shear zones in plutonic rocks intruding the volcanic rocks (similar to known gold occurrences in the La Ronge Domain in Saskatchewan; e.g., Lafrance, 1999).

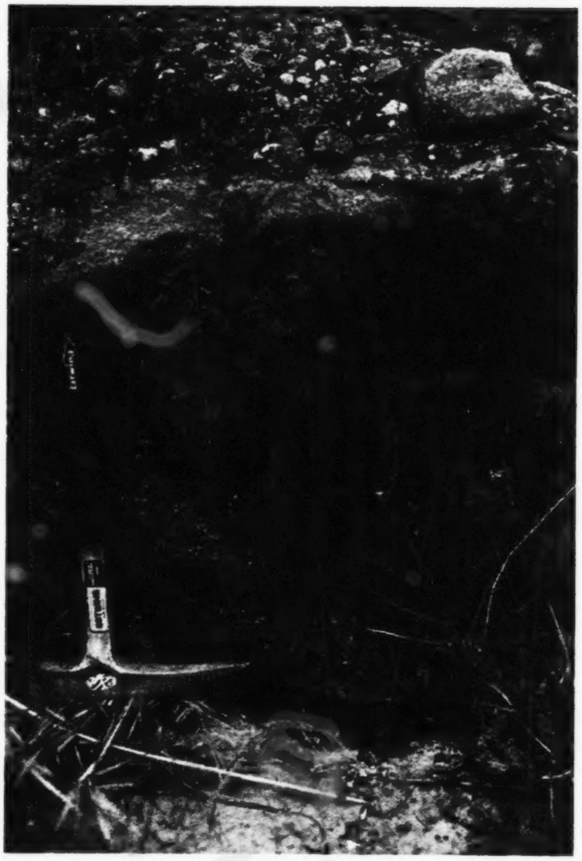


Figure GS-18-16: Migmatitic monzogranite showing small-scale tight folds and leucosome injections.

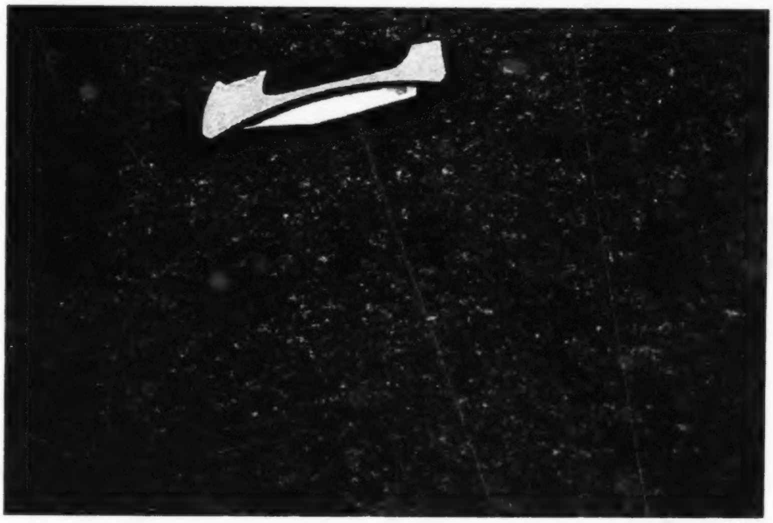


Figure GS-18-17: Coarse-grained biotite-hornblende monzogranite showing a weak foliation parallel to the knife. Note the nonmigmatitic texture and preservation of some of the coarser igneous feldspar crystals. Knife handle is 14 cm long.

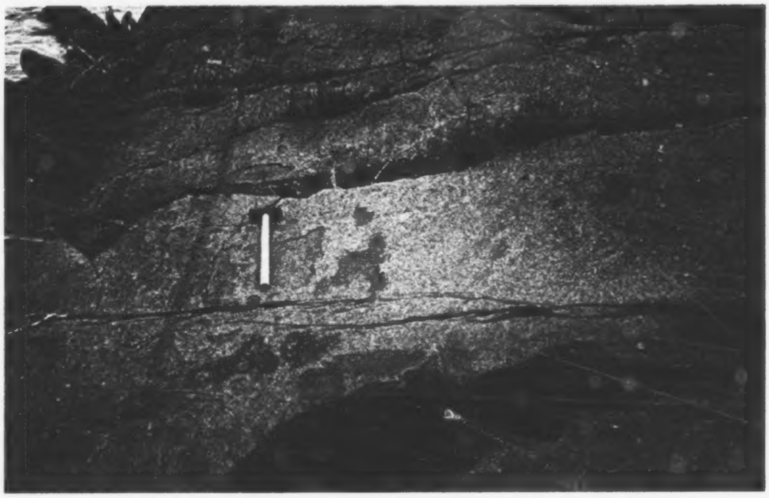


Figure GS-18-18: Elongate Black Trout diorite sill in Sickle Group, on an island in Granville lake. Note igneous layering (straight band to left of hammer). Dark band in foreground is black organic material. Igneous layering is parallel to the sill margins.

ACKNOWLEDGMENTS

The authors wish to thank Chris Beaumont-Smith, Herman Zwanzig, Tim Corkery and Adrian Park for invaluable logistical assistance and for having found time in their busy schedules to provide excellent and thought-provoking field trips. They would also like to extend their thanks to Jennifer Kavalench, Shannon Johns and David Rayner for their enthusiastic and capable assistance. Neill Brandsen once again provided thoughtful and professional logistical help. Review of an earlier version by Herman Zwanzig greatly improved this manuscript.

REFERENCES

Ames, D.E. and Taylor, C. 1996: Geology of the West Anomaly orebody, Ruttan volcanic-hosted massive sulphide deposit, Proterozoic Rusty Lake Belt; *in* EXTECH I: A Multidisciplinary Approach to Massive Sulphide Research in the Rusty Lake–Snow Lake Greenstone Belts, Manitoba, G.F. Bonham-Carter, A.G. Galley and G.M. Hall (ed.), Geological Survey of Canada, Bulletin 426, p. 45–76.

Ansdell, K.M. and Yang, H. 1995: Detrital zircons in the McLennan Group meta-arkoses and MacLean Lake Belt, western Trans-Hudson Orogen; *in* Trans-Hudson Orogen Transect, Report of Fifth Transect Meeting, April 3-4, 1995, Regina, Z. Hajnal and J. Lewry (ed.), LITHOPROBE Secretariat, University of British Columbia, LITHOPROBE Report No. 48, p.190–197.

Baldwin, D.A., Syme, E.C., Zwanzig, H.V., Gordon, T.M., Hunt, P.A. and Stevens, R.P. 1987: U-Pb zircon ages from the Lynn Lake and Rusty Lake metavolcanic belts, Manitoba: two ages of Proterozoic magmatism; Canadian Journal of Earth Sciences, v. 24, p. 1053–1063.

Barry, G.S. 1965: Trophy Lake area (east half); Manitoba Mines and Natural Resources, Mines Branch, Publication 63-3, Map 63-3, scale 1:63 360.

Barry, G.S., and Gait, R.I. 1966: Suwannee Lake area; Manitoba Mines and Natural Resources, Mines Branch, Publication 64-2, Map 64-2, scale 1:63 360.

Campbell, F.H.A. and Kendrick, G. 1972: Turnbull Lake; Manitoba Department of Mines, Resources and Environmental Management, Mines Branch, Publications 71-2D and 71-2E, Map 71-2-5, scale 1:50 000.

Corrigan, D. 2000a: Geology, central Reindeer Lake, Saskatchewan; Geological Survey of Canada, Open File 3750, scale 1:100 000.

Corrigan, D. 2000b: Geology, Milton Island area, Reindeer Lake south, Saskatchewan; Geological Survey of Canada, Open File 3881, scale 1:50 000.

Corrigan, D. 2001: Geology, northern Reindeer Lake, Saskatchewan; Geological Survey of Canada, Open File 3881, scale 1:100 000.

Corrigan, D., Bashforth, A. and Lucas, S. 1997: Geology and structural evolution of the La Ronge–Lynn Lake Belt in the Butler Island area (parts of 64D-9 and -10), Reindeer Lake, Saskatchewan; *in* Summary of Investigations 1997, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 97-4, p. 18–30.

Corrigan, D., MacHattie, T.G. and Chakungal, J. 1999a: The Wathaman Batholith and its relation to the Peter Lake Domain: insights from recent mapping along the Reindeer Lake transect, Trans-Hudson Orogen; *in* Summary of Investigations, 1999, Volume 2, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 99-4.2, p. 132–142.

Corrigan, D., MacHattie, T.G. and Chakungal, J. 2000: The nature of the Wathaman Batholith and its relationship to the Archean Peter Lake Domain along the Reindeer Lake transect, Saskatchewan; Geological Survey of Canada, Current Research 2000-C13, 10 p.

Corrigan, D., MacHattie, T.G., Piper, L., Wright, D., Pehrsson, S., Lassen, B. and Chakungal, J. 1998b: La Ronge–Lynn Lake Bridge Project: new mapping results from Deep Bay (parts of 64D-06 and -07) to north Porcupine Point (64E-07 and -08), Reindeer Lake; *in* Summary of Investigations 1998, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 98-4, p. 111–122.

Corrigan D., Maxeiner, R., Bashforth, A. and Lucas, S. 1998a: Preliminary report on the geology and tectonic history of the Trans-Hudson Orogen in the northwestern Reindeer Zone, Saskatchewan; *in* Current Research, Part C, Geological Survey of Canada, Paper 98-1C, p. 95–106.

Corrigan, D., Pehrsson, S.J., MacHattie, T.G., Piper, L., Wright, D., Lassen, B. and Chakungal, J. 1999b: Lithotectonic framework of the Trans-Hudson Orogen in the northwestern Reindeer Zone, Saskatchewan: an update from recent mapping along the Reindeer Lake Transect; *in* Current Research, Part C, Geological Survey of Canada, Paper 99-C, p. 169–178.

Corrigan, D., Therriault, A. and Rayner, N.M. 2001: Preliminary results from the Churchill River–Southern Indian Lake Targeted Geoscience Initiative; *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 94–107.

Cranstone, J.R. 1968: Watt Lake area (east half); Manitoba Mines and Natural Resources, Mines Branch, Publication 61-5 , Map 61-5, scale 1:63 360.

Cranstone, J.R. 1972: Geology of the Southern Indian Lake area, northeastern portion; Manitoba Department of Mines, Resources and Environmental Management, Mines Branch, Publication 71-2J.

Fumerton, S.L., Stauffer, M.R. and Lewry, J.F. 1984: The Wathaman Batholith: largest known Precambrian pluton; Canadian Journal of Earth Sciences, v. 21, p. 1082–1097.

Harper, C.T. 1998: The La Ronge Domain–Glennie Domain transition: Street Lake area (parts of NTS 64D-3 and -6); *in* Summary of Investigations 1998, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 98-4, p. 66–80.

Kaszycki, C.A., Suttner, W. and DiLabio, R.N.W. 1988: Gold and arsenic in till, Wheatcroft Lake dispersal train, Manitoba; *in* Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 341–351.

Lafrance, B. 1999: Gold studies in the Byers Fault–Waddy Lake area, La Ronge Domain; *in* Summary of Investigations 1999, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 99-4.2, p. 202–207.

Lewry, J.F. and Collerson, K.D. 1990: The trans-Hudson Orogen: extent, subdivision and problems; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 1–14.

Manitoba Energy and Mines 1986a: Granville Lake; Manitoba Energy and Mines, Minerals Division, Bedrock Geology Compilation Series, NTS 64C, scale 1:250 000.

Manitoba Energy and Mines 1986b: Uhlman Lake; Manitoba Energy and Mines, Minerals Division, Bedrock Geology Compilation Series, NTS 64B, scale 1:250 000.

Manitoba Energy and Mines 1990: Big Sand Lake; Manitoba Energy and Mines, Minerals Division, Bedrock Geology Compilation Series, NTS 64G, scale 1:250 000.

Maxeiner, R.O., Corrigan, D., Harper, C.T., MacDougall, D.G. and Ansdell, K.M. 2001: Lithogeochemistry, economic potential and plate tectonic evolution of the 'La Ronge–Lynn Lake Bridge', Trans-Hudson Orogen; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 2001-4.2, p. 87–110.

Meyer, M.T., Bickford, M.E. and Lewry, J.F. 1992: The Wathaman Batholith: an early Proterozoic arc in the Trans-Hudson orogenic belt, Canada; Geological Society of America Bulletin, v. 104, p. 1073–1085.

Stauffer, M.R. 1990: The Missi Formation: an Aphebian molasse deposit in the Reindeer Lake Zone of the Trans-Hudson Orogen, Canada; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 121–141.

Syme, E.C. 1985: Geochemistry of metavolcanic rocks in the Lynn Lake Belt; Manitoba Energy and Mines, Geological Report GR85-1, 84 p.

Thomas, D.J. 1993: Geology of the Star Lake–Otter Lake portion of the Central Metavolcanic Belt, La Ronge Domain; Saskatchewan Energy and Mines, Report 236, 132 p.

Van Schmus, W.R. and Schledewitz, D.C.P. 1986: U-Pb zircon geochronology of the Big Sand Lake area, northern Manitoba; *in* Report of Field Activities 1986, Manitoba Energy and Mines, Minerals Division, p. 207–210.

Yeo, G. 1998: A systems tract approach to the stratigraphy of paragneisses in the southeastern Wollaston Domain; *in* Summary of Investigations 1998, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 98-4, p. 36–47.

Zwanzig, H.V. 1981: Watt Lake northeast; Manitoba Department of Energy and Mines, Mineral Resources Division, Preliminary Map 1980 L-1; scale 1:20 000.

Zwanzig, H.V. 1990: Kisseynew gneiss belt in Manitoba: stratigraphy, structure, and tectonic evolution; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 95–120.

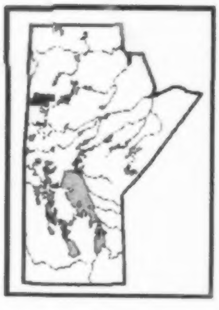
Zwanzig, H.V. 2000: Geochemistry and tectonic framework of the Kisseynew Domain–Lynn Lake Belt boundary (part of NTS 63P/13); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 91–96.

Zwanzig, H.V. and Cameron, H.D.M. 2002: Geology of Suwannee Lake (northwest) and Trophy Lake (northeast); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Preliminary Map PMAP2002-3; 1:20 000.

Zwanzig, H.V., Syme, E.C. and Gilbert, H.P. 1999: Updated trace element geochemistry of ca. 1.90 Ga metavolcanic rocks in the Paleoproterozoic Lynn Lake Belt; Manitoba Industry, Trade and Mines, Geological Services, Open File Report OF99-13, 46 p. and Map 99-13-1 at 1:100 000 scale.

GS-19 STRUCTURAL ANALYSIS AND GEOCHRONOLOGICAL STUDIES IN THE LYNN LAKE GREENSTONE BELT AND ITS GOLD-BEARING SHEAR ZONES (NTS 64C10, 11, 12, 14, 15 AND 16), MANITOBA

by C.J. Beaumont-Smith and Ch.O. Böhm[1]



Beaumont-Smith, C.J. and Böhm, Ch.O. 2002: Structural analysis and geochronological studies in the Lynn Lake greenstone belt and its gold-bearing shear zones (NTS 64C10, 11, 12, 14, 15 and 16), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 159-170.

SUMMARY

The application of U-Pb geochronology and Sm-Nd isotopic studies to the continuing structural analysis of the Lynn Lake greenstone belt has elucidated the tectonometamorphic and metallogenic history of the greenstone belt. The complex volcanic tectonostratigraphy assembled during D_1 reflects the juxtaposition of ca. 1890 Ma, weakly contaminated volcanic rocks of the northern Lynn Lake belt with juvenile-arc volcanic rocks of the southern Lynn Lake belt, the age of which is currently under investigation.

The deformed, assembled greenstones acted as basement for the emplacement of successor-arc plutons that are as old as ca. 1875 to 1871 Ma. At least some of the volcanic rocks in the southern belt are therefore thought to be older than 1875 Ma, although two rhyolite bodies yield U-Pb zircon ages as young as ca. 1842 Ma and felsic plutons give ages of 1857 and 1830 to 1820 Ma. Deposition of fluvial-alluvial sediments took place prior to the ca. 1830 Ma plutonism. The greenstone belt was subsequently deformed by an intense D_2 deformation, which transposed the belt into an east-west structural trend and produced regional, dextral transpressional shear zones at ca. 1819 to 1815 Ma. This was closely followed by the peak of regional metamorphism at ca. 1814 Ma. Late synkinematic magmatism and possible associated contact metamorphism coincided with northeast-trending D_4 deformation structures at ca. 1784 Ma.

INTRODUCTION

Understanding the relationship between regional tectonic evolution and metallogeny is a fundamental aspect of successful mineral exploration. In an effort to encourage and support mineral exploration in northwestern Manitoba, a joint program focusing on the tectonic evolution of the northern Trans-Hudson Orogen (Hoffman, 1990) was initiated by the Manitoba Geological Survey (MGS) and the Geological Survey of Canada (GSC), under the auspices of the Targeted Geoscience Initiative (TGI). One component of the MGS contribution to the TGI is a program of detailed structural analysis and isotopic studies of the Lynn Lake greenstone belt, with a focus on gold metallogeny.

The structural analysis of the Lynn Lake greenstone belt was initiated in 1999 and focused on the relationship between the Johnson Shear Zone (Bateman, 1945) and gold mineralization hosted by the shear zone (*see* Beaumont-Smith and Rogge, 1999). The development of shear zones and the associated gold deposition were recognized to have a regional extent in the Lynn Lake greenstone belt. This realization resulted in the expansion of the project to include an appraisal of the deformation history and gold metallogeny of the entire belt (Beaumont-Smith, 2000; Jones et al., 2000; Ma et al., 2000). In 2001, an isotopic study of the Lynn Lake belt was added to the project, in order to provide time constraints and to integrate the structural data into a coherent tectonic framework.

GEOLOGICAL SETTING AND STRUCTURAL OVERVIEW

The Lynn Lake greenstone belt represents a Paleoproterozoic metavolcanic belt located along the northern margin of the Kisseynew sedimentary basin (Fig. GS-19-1), within the internal Reindeer Zone (Stauffer, 1984; Lewry and Collerson, 1990) of the Trans-Hudson Orogen. It comprises a diverse tectonostratigraphy collectively assigned to the Wasekwan Group (Bateman, 1945). The various metavolcanic units with differing tectonic affinities (Zwanzig et al., 1999) are structurally juxtaposed to form two east-trending, steeply north-dipping supracrustal belts.

The northern belt consists of submarine, tholeiitic, mafic metavolcanic and metavolcaniclastic rocks interpreted to represent an overall north-facing, steeply dipping succession (Gilbert et al., 1980). The north belt includes the Agassiz Metallotect (Fedikow and Gale, 1982), a tectonostratigraphic assemblage consisting of ultramafic flows (picrite), banded oxide facies iron formation and associated exhalative sedimentary rocks. The Agassiz Metallotect is a relatively narrow, strike-continuous, stratigraphic-structural unit that occurs along a significant portion of the northern belt (*see* Ma et al., 2000; Ma and Beaumont-Smith, 2001; Park et al., GS-20, this volume). The northern belt is unconformably overlain to the north by marine sedimentary rocks, the Ralph Lake conglomerate and Zed Lake greywacke (Gilbert et

---

[1] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3

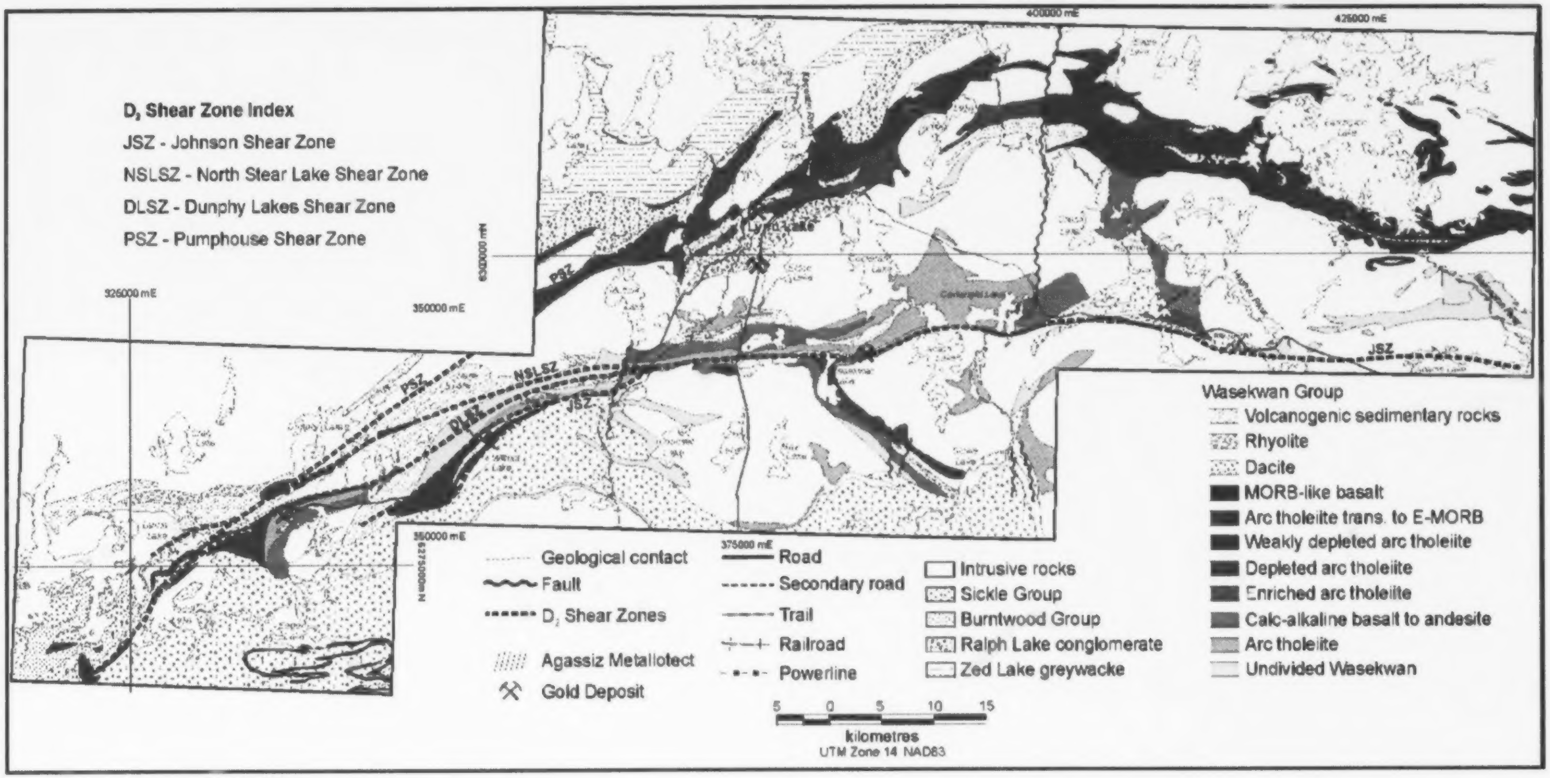

D2 Shear Zone Index
JSZ - Johnson Shear Zone
NSLSZ - North Stear Lake Shear Zone
DLSZ - Dunphy Lakes Shear Zone
PSZ - Pumphouse Shear Zone
325000 mE
350000 mE
375000 mE
400000 mE
425000 mE
6300000 mN
6275000m N
PSZ
NSLSZ
DLSZ
JSZ
Lynn Lake
Geological contact
Fault
D2 Shear Zones
Agassiz Metallotect
Gold Deposit
Road
Secondary road
Trail
Railroad
Powerline
Intrusive rocks
Sickle Group
Burntwood Group
Ralph Lake conglomerate
Zed Lake greywacke
Wasekwan Group
Volcanogenic sedimentary rocks
Rhyolite
Dacite
MORB-like basalt
Arc tholeiite trans. to E-MORB
Weakly depleted arc tholeiite
Depleted arc tholeiite
Enriched arc tholeiite
Calc-alkaline basalt to andesite
Arc tholeiite
Undivided Wasekwan
5 0 5 10 15
kilometres
UTM Zone 14 NAD83

Figure GS-19-1: General geology of the Lynn Lake greenstone belt.

al., 1980), and is intruded by the 1876 Ma (Baldwin et al., 1987) to1871 Ma (Turek et al., 2000) Pool Lake intrusive suite (Manitoba Energy and Mines, 1986) and younger plutons (the post-Sickle plutons of Milligan, 1960).

The southern belt is composed of submarine, tholeiitic to calc-alkaline, metavolcanic and metavolcaniclastic rocks with minor amounts of mid-oceanic ridge basalt (MORB). The southern belt is separated from the northern belt by plutons of the Pool Lake suite. To the south, the southern belt is unconformably overlain and structurally underlain by Sickle Group (Norman, 1933) fluvial-alluvial conglomerate and arkosic sedimentary rocks. The Sickle Group also unconformably overlies the Pool Lake intrusive suite, and the basal conglomerate is characterized by a high proportion of Pool Lake–type plutonic clasts. The tectonic juxtaposition of the volcanic rocks in the northern and southern belts occurred prior to emplacement of the Pool Lake suite and deposition of the Sickle Group. The age of the Sickle Group has not been determined directly, but its composition, stratigraphic position and contact relations correlate well with the 1850 to 1840 Ma MacLennan Group in the La Ronge greenstone belt in Saskatchewan (Ansdell et al., 1999).

Two younger suites of plutons, which yield ages of 1857 Ma (Machado, unpublished data, 2000) and 1832 Ma (Turek et al., 2000), do not have clearly defined contact relations, but emplacement into the Sickle Group is suggested locally. These magmatic ages are consistent with the subdivision of intrusive rocks into early, middle and late successor-arc plutons, as applied in the Flin Flon Belt (Whalen et al., 1999), and suggest a similar complex magmatic evolution in the Lynn Lake greenstone belt.

The structural evolution of the Lynn Lake greenstone belt is the product of six regionally penetrative, ductile deformation events (D_1–D_6). The assembly of the diverse volcanic tectonostratigraphy that characterizes the greenstone belt constitutes D_1. This deformation occurred prior to intense transposition of the belt.

The D_2 transpression of the greenstone belt resulted from tight to isoclinal folding of the D_1 structural geometry. Intense D_2 deformation produced the penetrative, S_2, differentiated regional foliation present in all rock types; accordingly, D_2 deformation postdates intrusion of the youngest plutons and deposition of the Sickle Group. The plunge of F_2 folds is variable, but appears to vary systematically as a function of D_2 strain. In areas of lower D_2 strain, the plunge of F_2 is generally shallow, increasing in concert with increasing D_2 strain. The shallow F_2 plunge in areas of lower D_2 strain suggests the D_1 structural geometry was characterized by shallow dips, which were steepened to subvertical as a result of tight to isoclinal F_2 folding. The steepening of F_2 plunge corresponds to the development of D_2 shear zones throughout the greenstone belt. This reflects the evolution from fold-dominated deformation during the early stages of D_2 shortening, to dextral shear zone development during the later stages of the deformation.

This change may reflect a strain-hardening effect as F_2 folds tighten or as the succession became recrystallized and intruded by the Pool Lake suite. The initial shear zones developed on F_2 fold limbs and subsequently coalesced into broad, regional-scale shear zones. The kinematic framework of D_2 shear zones is characterized by dextral transcurrent shear fabrics and generally steep stretching lineations. This is consistent with their development in response to dextral transpression (Lin et al., 1998). Regional-scale D_2 shear zones represent an important exploration target, hosting the majority of known gold deposits in the northern and southern volcanic belts (Beaumont-Smith and Rogge, 1999; Beaumont-Smith 2000; Beaumont-Smith and Edwards, 2000; Jones et al., 2000; Ma et al., 2000).

The most significant D_2 shear zones are the Johnson Shear Zone (Bateman, 1945), located along the southern margin of the southern greenstone belt, and a similar zone within the Agassiz Metallotect (Ma et al., 2000), located in the northern belt. The Johnson Shear Zone (JSZ) is a dextral transpressive shear zone that has been delineated eastward to the Adams Lake area and westward to the Dunphy Lakes area (Beaumont-Smith et al., 2001, and references therein). The JSZ hosts the known gold deposits and occurrences in the southern belt. Similarly, D_2 shear was an important process in the development of the Agassiz Metallotect. Recognition of D_2 shear zones in both the northern and southern belts demonstrates the regional nature of the D_2 shear zone development.

The structural geometry of the greenstone belt is largely the product of D_1-D_2 interference. Subsequent deformations have had little macroscopic effect on this geometry. Fabric elements that make up the D_3 and D_4 deformations include tight S- and Z-asymmetrical chevron folds and associated crenulation cleavage, respectively. The D_3 fabrics trend northwest, whereas D_4 fabrics trend northeast. Although mesoscopic fabric elements for the respective deformations are regionally penetrative, the deformations have not significantly reoriented the regional D_2 structural trend. Exceptions to this are found in the Boiley Lake area, where the distribution of the Wasekwan Group south of the Johnson Shear Zone is controlled by a large, F_3, S-asymmetrical fold, and in the MacLellan mine area, where the Agassiz Metallotect is folded by a macroscopic, northeast-trending F_4 fold (Park et al., GS-20, this volume).

The kilometre-scale open folds of the regional east-west D_2 structural trend are the result of D_5. Mesoscopic fabrics associated with this deformation include open F_5 conjugate folds, kink bands and open crenulations. A north-trending, spaced, S_5 fracture cleavage is also common. These structures are penetrative at regional scale, but are not mesoscopically penetrative.

The final deformation (D_6) involves the brittle-ductile reactivation of D_2 shear zones, characterized by the development of pseudotachylite zones that overprint all other fabric elements. The reactivation is dominated by sinistral transcurrent movement within narrow zones in the D_2 shear zones. The T_1 fault in the footwall of the Burnt Timber gold deposit is a D_6 structure (*see* Peck et al., 1997, 1998).

Metamorphic grade in the Lynn Lake belt increases westward across the belt from upper greenschist facies to upper amphibolite facies. The relationship between deformational fabrics and metamorphic porphyroblasts indicates that metamorphism is the product of at least two thermal events. The oldest metamorphic event (M_1) reflects contact metamorphism associated with emplacement of the Pool Lake intrusive suite, as well as the younger, post-Sickle plutons. Porphyroblasts formed during M_1 are overprinted by regional D_2 fabric development. The M_1 metamorphism represents multiple, relatively closely spaced events. The regional metamorphic event (M_2) overprints M_1 porphyroblasts and is broadly coincident with D_4. The timing of M_2 does not correlate with any known magmatic event in the belt, and is characterized by the growth of low-pressure, moderate- to high-temperature assemblages.

STRUCTURAL ANALYSIS: NEW RESULTS

Structural analysis undertaken during the 2002 field season concentrated on the delineation of D_2 shear zones in the western portion of the greenstone belt and the relationship between shear-zone development in the northern and southern belts. The GIS analysis of available datasets for the Lynn Lake greenstone belt identified potential areas of D_2 shear-zone development in the Dunphy Lakes area (Rogge, 2002; Rogge et al., 2000). The postulated pattern of high "deformation potential zones" reflected the truncation of the east-trending Johnson Shear Zone by a northeast-trending structural lineament west of Dunphy Lakes. This structure corresponds to known D_2 shear-zone development within the Agassiz Metallotect in the MacLellan mine area (see Rogge, 2002), but delineation of this structure west of Sheila Lake was incomplete.

Detailed structural analysis in the Dunphy Lakes area has recently identified several D_2 shear zones. A broad area of high strain is developed along the southern shore of Dunphy Lakes (Fig. GS-19-2). This zone, the Dunphy Lakes Shear Zone (DLSZ), is characterized by a steep south to north strain gradient, culminating in a 50 m wide mylonitic core. The kinematics of the mylonite zone are consistent with those of other D_2 shear zones, with dextral transcurrent shear fabrics and a steep stretching lineation. This shear zone correlates with the Dunphy Lake Fault (Gilbert et al., 1980) and has been previously interpreted as the western extension of the JSZ (Beaumont-Smith, 2000). In this area, a D_2 shear zone is located along the contact between the Fox mine tonalite (Turek et al., 2000) and the volcanic rocks. The latter have experienced significant transposition, producing layered tectonite units and tectonic intercalation of Fox mine arc tholeiite, Hatchet Lake MORB basalt, Snake Lake dacite and Wasekwan Group epiclastic sedimentary rocks.

A second D_2 high-strain zone, the Pumphouse Shear Zone (PSZ), has been identified within the belt of supracrustal rocks that trends northeast across the central portion of Dunphy Lakes (Fig. GS-19-2). The Wasekwan Group rocks that make up this belt are intensely foliated, making the protoliths difficult to determine. Slight compositional variations of the tectonic layering developed in these rocks suggests that the original stratigraphy consisted of mafic volcanic rocks and lesser amounts of epiclastic sedimentary rocks. The layering has experienced penetrative foliation boudinage of the mafic layers, consistent with high non-coaxial strains, which appears to reflect the localization of regional D_2 deformation into the supracrustal rocks. The contacts with the Fox mine tonalite to the south and the undated intrusive rocks to the north are mylonitized and characterized by a steep strain gradient that decays rapidly away from the supracrustal belt. The dextral transpressive kinematics of this mylonite zone are similar to those of other D_2 shear zones.

The extreme glacial cover east of Dunphy Lakes prevents the delineation of the DLSZ and the PSZ immediately east of the lakes. The lack of geological constraints in this area presents a problem for correlation of the shear zones delineated in the Dunphy Lakes area and the numerous JSZ splays west of Gemmell Lake (*see* Beaumont-Smith, 2000). Geological mapping southeast of Dunphy Lakes has not identified additional high-strain zones other than a broad protomylonite zone developed along the contact between the Wasekwan and Sickle groups, immediately west of Wilmot Lake. This zone is probably the continuation of the southern splay of the JSZ. The DLSZ was interpreted to be the westward continuation of the central JSZ splay that extends along the north shore of Gemmell Lake (Beaumont-Smith et al., 2001), and there is no compelling evidence to modify this correlation.

Correlating the PSZ with previously delineated shear zones east of Dunphy Lakes is more problematic. The northeast trend of the PSZ corresponds to the structure proposed by Rogge (2002). Reconnaissance geological mapping north of Motriuk Lake has identified a broad area of high strain. This zone is developed within a thin unit of Wasekwan Group mafic epiclastic rocks separating thick units of mafic and felsic volcanic rocks, reflecting the localization of D_2 strain into the least competent member of the local stratigraphy. The correlation of the PSZ and this high-strain zone with the northeast-trending zone of high deformation potential proposed by Rogge (2002) is compelling. Alternatively,

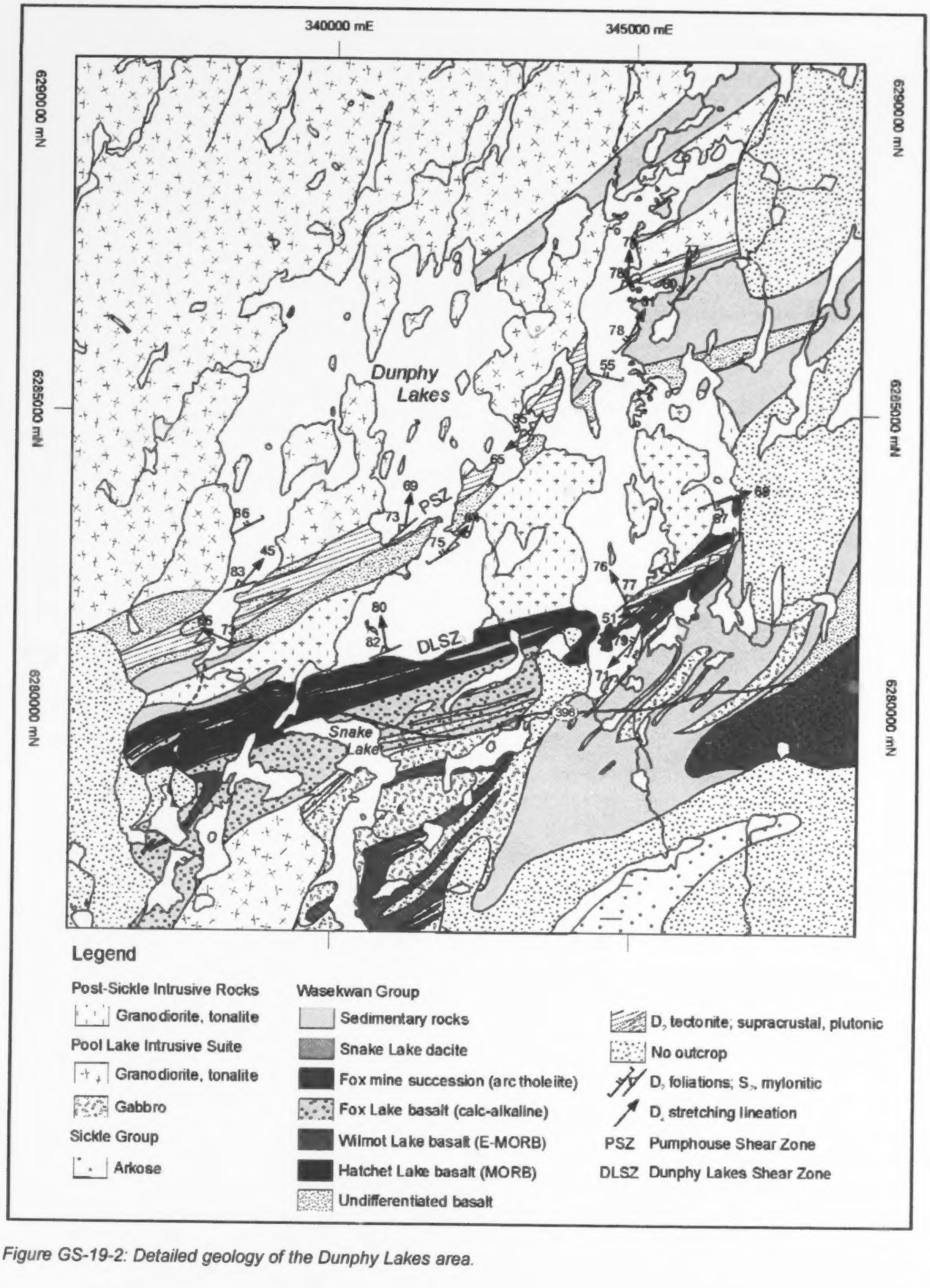

340000 mE
345000 mE
6290000 mN
6285000 mN
6280000 mN
Dunphy Lakes
Snake Lake
PSZ
DLSZ
396
76
78
60
81
78
55
55
65
69
73
75
66
86
45
83
66
73
80
82
76
77
51
79
71
68
67
Legend
Post-Sickle Intrusive Rocks
Granodiorite, tonalite
Pool Lake Intrusive Suite
Granodiorite, tonalite
Gabbro
Sickle Group
Arkose
Wasekwan Group
Sedimentary rocks
Snake Lake dacite
Fox mine succession (arc tholeiite)
Fox Lake basalt (calc-alkaline)
Wilmot Lake basalt (E-MORB)
Hatchet Lake basalt (MORB)
Undifferentiated basalt
D_2 tectonite; supracrustal, plutonic
No outcrop
D_2 foliations; S_{2m} mylonitic
D_2 stretching lineation
PSZ Pumphouse Shear Zone
DLSZ Dunphy Lakes Shear Zone

Figure GS-19-2: Detailed geology of the Dunphy Lakes area.

the westward continuation of the North Stear Lake Shear Zone (NSLSZ) has not been adequately delineated, so the relationship between it and the PSZ remains uncertain (cf. Beaumont-Smith et al., 2001). Exploration-company geophysical data clearly delineate the NSLSZ west from the Stear Lake area, where the shear zone outcrops, to the southern tip of Irene Lake (limit of geophysical coverage). Whether the NSLSZ is a splay of the PSZ or is truncated by the PSZ remains uncertain.

Identification of a large number of D_2 shear zones in the Dunphy Lakes area demonstrates that the western portion of the Lynn Lake greenstone belt hosts areas of high gold-mineralization potential. Although the relationship between the various shear zones remains poorly understood, many of the exposed portions of the shear zones host alteration favourable for gold mineralization, and several areas of gold mineralization have been identified (*see* Beaumont-Smith, 2000; Beaumont-Smith et al., 2001; Rogge, 2002).

ISOTOPE GEOLOGY

During the 2001 and 2002 field seasons, a total of 35 samples (10–20 kg of clean, relatively unaltered and homogeneous rock material) were collected for Sm-Nd isotope and/or U-Pb geochronology analysis (Fig. GS-19-3). The aim of this ongoing study is to integrate Sm-Nd isotope and U-Pb geochronological results into detailed structural and petrographic field studies, in order to establish a framework for the tectonic evolution of the Lynn Lake greenstone belt and provide a better understanding of the timing and nature of deformational, metamorphic and mineralizing events, particularly the development of D_2 gold-bearing shear zones.

Timing of felsic volcanism

Preliminary geochronological data from the northern and southern Lynn Lake belts indicate that the two belts include volcanic rocks of significantly different ages. The sample suite from the present northern belt consists of two samples from the Lynn Lake rhyolite, one from the western portion of the body and the other of the northern phase from the eastern portion of the body. Together, these two samples represent the southern and northern phases of the Lynn Lake main rhyolite body as defined by Baldwin (1983). At present, sampling of the southern belt has targeted all the major felsic volcanic bodies and a series of smaller felsic tuffaceous units intercalated with the mafic volcanic stratigraphy. Five felsic volcanic samples have been processed to date, of which two yielded datable zircons.

The age of felsic volcanism in the northern belt has been determined by U-Pb isotpic dating of prismatic euhedral, magnetic zircon crystals (0.8–1.2 Amps) from the two Lynn Lake rhyolite samples. A quartz-plagioclase–phyric sample from the eastern portion of the Lynn Lake rhyolite (northern phase) provided an age of 1892 ± 3 Ma. Two U-Pb analyses of magnetic zircon from the western, southern phase of the Lynn Lake rhyolite provided an age of 1886 ± 1.5 Ma. Most important, these new ages are significantly younger than the ca. 1910 Ma age reported by Baldwin et al. (1987), but contemporaneous with ca. 1.90 to 1.88 Ga felsic volcanism in the Flin Flon Belt (e.g., Lucas et al., 1996).

Compared to the northern belt, the age of felsic volcanism in the southern belt seems much more difficult to determine, and the following results are only preliminary. The poor zircon yield to date, particularly involving the larger, strongly sheared and silicified rhyolitic units, has necessitated additional sampling in 2002. At present, the age of southern belt volcanism is based on U-Pb age dating of two thin rhyodacite units in the Gemmell Lake (west) and One Island Lake (east) areas. Two analyses of zircon fragments from the Gemmell Lake rhyodacite sample returned an age of 1856 ± 2 Ma, and the One Island Lake rhyodacite yielded an age of ca. 1842 Ma based on a three single-grain analyses. Although these ages are preliminary and require additional analyses, they might represent the first direct evidence for the presence of units with a much younger age of volcanism in the southern belt compared to the northern belt. Nevertheless, plutons of the ca. 1876 to 1871 Ma Pool Lake intrusive suite cut across the main units in the southern belt (Gilbert et al., 1980) and indicate that an older period of volcanism is also present. Further geochronology on southern belt rhyolite and plutons with known contact relations is required to confirm this inference.

The different age ranges of felsic volcanism in the northern and southern belts are also reflected in the Sm-Nd isotope results. The five samples of felsic volcanic rocks from the southern Lynn Lake greenstone belt are relatively juvenile (T_{CR} Nd model ages (Goldstein et al., 1984) of ca. 2.1 Ga and initial ε_{Nd} of approx. +2 to +4; *see also* explanations in Zwanzig and Böhm, GS-14, this volume). This is in contrast to the two samples from the Lynn Lake rhyolite in the north belt, which yielded significantly older Nd isotopic signatures with Nd model ages of ca. 2.5 Ga and initial ε_{Nd} of approx. 0 to –0.5, clearly indicating the involvement of crust that is greater than 2.0 Ga, possibly Neoarchean. A Nd isotopic discontinuity between the northern and southern belts probably represents a cryptic crustal boundary between the belts. This correlates with differences in the trace-element geochemistry of the two belts

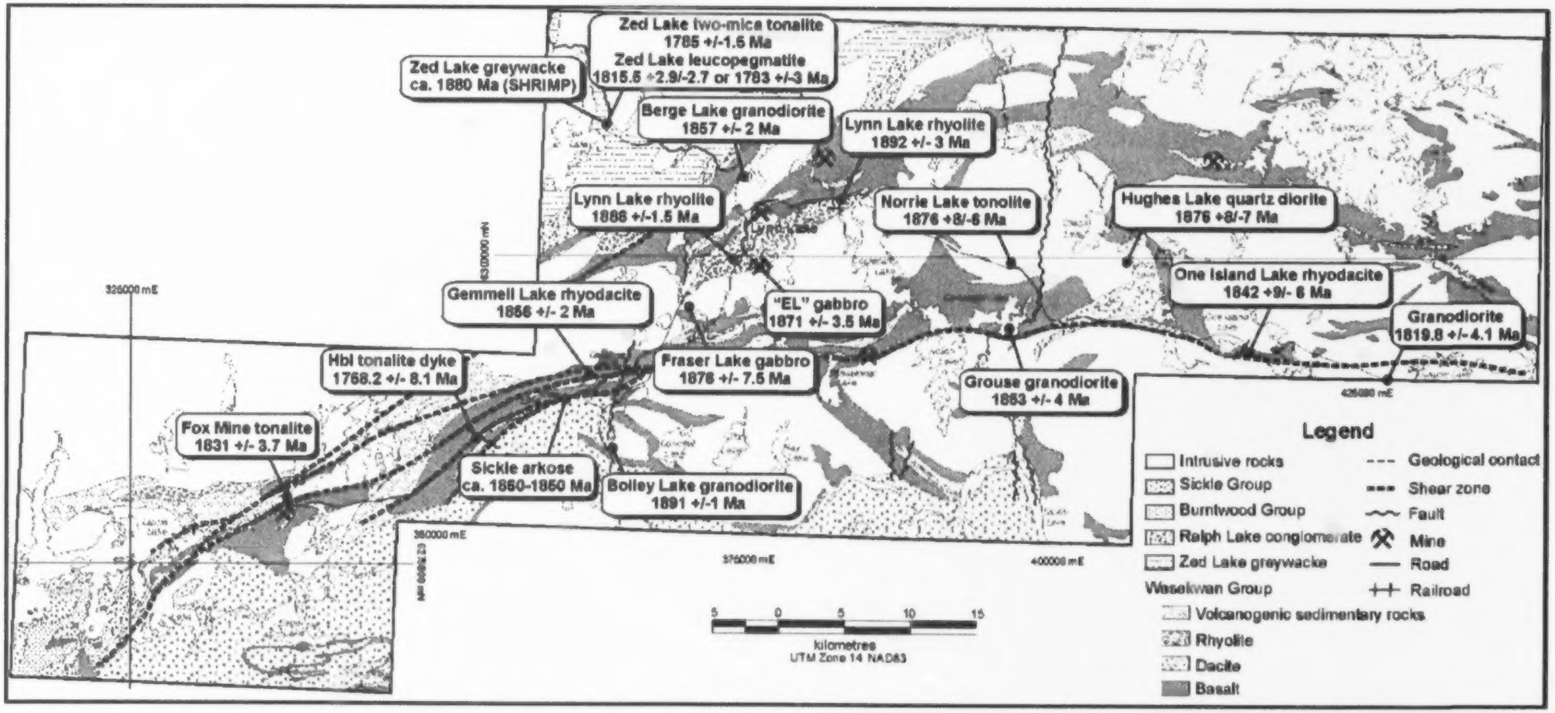

Zed Lake two-mica tonalite
1785 +/-1.5 Ma
Zed Lake leucopegmatite
1815.5 +2.9/-2.7 or 1783 +/-3 Ma
Zed Lake greywacke
ca. 1880 Ma (SHRIMP)
Berge Lake granodiorite
1857 +/- 2 Ma
Lynn Lake rhyolite
1892 +/- 3 Ma
Lynn Lake rhyolite
1888 +/-1.5 Ma
Norrie Lake tonolite
1876 +8/-6 Ma
Hughes Lake quartz diorite
1876 +8/-7 Ma
Gemmell Lake rhyodacite
1856 +/- 2 Ma
"EL" gabbro
1871 +/- 3.5 Ma
One Island Lake rhyodacite
1842 +9/- 6 Ma
Granodiorite
1819.8 +/- 4.1 Ma
Hbl tonalite dyke
1768.2 +/- 8.1 Ma
Fraser Lake gabbro
1876 +/- 7.5 Ma
Grouse granodiorite
1853 +/- 4 Ma
Fox Mine tonalite
1831 +/- 3.7 Ma
Sickle arkose
ca. 1860-1850 Ma
Bolley Lake granodiorite
1891 +/-1 Ma
325000 mE
6300000 mN
350000 mE
6275000 mN
375000 mE
400000 mE
425000 mE
Lynn Lake
5
0
5
10
15
kilometres
UTM Zone 14 NAD83
Legend
Intrusive rocks
Sickle Group
Burntwood Group
Ralph Lake conglomerate
Zed Lake greywacke
Wasekwan Group
Volcanogenic sedimentary rocks
Rhyolite
Dacite
Basalt
Geological contact
Shear zone
Fault
Mine
Road
Railroad

Figure GS-19-3: Locations of isotope geology samples.

(Zwanzig et al., 1999), indicating differences in the tectonic affinities of the constituent volcanic rocks. This boundary should therefore be located in the Fraser Lake–south Eldon Lake area, north of the Johnson Shear Zone (Fig. GS-19-2).

Timing of felsic plutonism

The U-Pb geochronological studies by Turek et al. (2000) and Baldwin et al. (1987) suggested multiple ages of felsic plutonism, at ca. 1876, 1871 and 1831 Ma, that postdate main accretion of the Lynn Lake greenstone belt. Additional unpublished data (Machado, pers. comm., 2000) identify another period of felsic magmatism at ca. 1857 Ma. One aim of this project was to test and complement these data with samples of additional, structurally well-constrained, felsic intrusive bodies and to characterize their geotectonic setting.

Coarse-grained, weakly feldspar-phyric granodiorite from the southeastern Lynn Lake belt forms abundant, pre- or syn-D_2 injection lits in quartz diorite. A sample of the granodiorite yielded a U-Pb zircon crystallization age of 1818.6 +1.2/–1.4 Ma that also represents a maximum age of D_2 deformation in the area (*see* below). Furthermore, the granodiorite has a T_{CR} Nd model age of ca 2.1 Ga, corresponding to ε_{Nd} of approx. +2 at 1820 Ma, which indicates a relatively juvenile crustal origin without significant involvement of older, Archean crust.

A different granodiorite body was sampled at southeastern Boiley Lake in the southern Lynn Lake belt, south of the JSZ. Outcrop and map relationships indicate that the Boiley Lake granodiorite is intrusive into the Sickle Group metasedimentary rocks north of Boiley Lake. Preliminary zircon age data from the Boiley Lake granodiorite, however, suggest a crystallization age of ca. 1891 Ma. Although the timing of felsic volcanism in the southern Lynn Lake belt is poorly constrained at present and might be as young as ca. 1850 Ma (*see* above), the 1890 Ma felsic intrusive age is similar to the ca. 1892 Ma age of felsic volcanism in the northern Lynn Lake belt. The Boiley Lake granodiorite might represent a subvolcanic intrusion, a theory which could be tested using geochemistry. Alternatively, and similar to the Flin Flon Belt, the Boiley Lake granodiorite might form part of a previously unknown, evolved-arc assemblage that predates main accretion of the Lynn Lake belt. This corresponds to the change in the geochemistry of the mafic volcanic rocks south of the JSZ, which trend toward E-MORB, as opposed to the arc tholeiites that dominate the southern part of the belt, north of the JSZ (Zwanzig et al., 1999).

Timing of tectonometamorphism

In an effort to constrain the timing of the deformational events and the emplacement of gold mineralization, U-Pb dating has been applied to samples where the detailed structural relationships between deformational fabric elements and intrusive units are known. This, in turn, constrains the timing of gold mineralization, as the emplacement of the associated alteration assemblages are hosted by D_2 shear zones and appear to result from syn-D_2 hydrothermal activity, which predates the peak of regional metamorphism and D_4 (Beaumont-Smith and Rogge, 1999).

The age of D_2 is constrained by a leucogranitic pegmatite at Zed Lake (northern margin of the northern Lynn Lake belt), which formed during (the late stage of) D_2, the main regional phase of deformation. The U-Pb zircon and monazite age data suggest that the Zed Lake leucogranitic pegmatite was emplaced at 1815 ± 3 Ma and subsequently metamorphosed at ca. 1783 ± 3 Ma.

A sample of the syn-D_4 tonalite dikes from the southwestern Lynn Lake belt, in comparison, yielded rare zircons with an age of 1758 ± 8 Ma. Together with the 1819 ± 1 Ma age of pre- or syn-D_2 granodiorite injection in the southeastern Lynn Lake belt (*see* above), it is most likely that the age of D_2 is ca. 1815 to 1819 Ma, and that the Zed Lake leucogranitic pegmatite and the tonalite dikes were formed or metamorphosed at ca. 1785 and 1758 Ma, respectively, prior to or during D_4.

To date, the age of regional metamorphism is less well constrained. The present best estimate comes from the One Island Lake rhyodacite sample (southern belt), which yielded a preliminary U-Pb age from a metamorphic zircon crystal of ca. 1814 Ma, in addition to the ca. 1842 Ma primary zircon age. These preliminary data suggest that the peak of regional metamorphism is contemporaneous with, or slightly younger than, the timing of D_2, possibly coincident with the timing of gold mineralization. The persistent recrystallization of D_2 fabrics supports the latter. The younger, possibly metamorphic zircons from the Zed Lake area may indicate one or more metamorphic events of probable contact origin associated with the emplacement of ca. 1784 Ma or younger plutons.

Sediment provenance and timing of sedimentation

Paragneiss samples from the dominantly turbiditic, volcanic-derived Wasekwan Group and Zed Lake greywacke, and from the dominantly fluvial-alluvial meta-arkosic to arenitic Sickle Group, were studied.

The Sm-Nd isotope and U-Pb zircon results indicate that a Sickle Group meta-arkose sample from the southwestern Lynn Lake belt is composed mainly of less than 2.0 Ga (1.85–1.9 Ga) and smaller amounts of pre-2.0 Ga (2.4–2.5 Ga and/or 2.6–2.7 Ga) detritus (T_{CR} Nd model age of ca. 2.3 Ga, corresponding to ε_{Nd} of +0.3 at 1850 Ma), and was probably metamorphosed at ca. 1830 Ma (platy, metamorphic zircon). Accordingly, the Sickle Group is older than 1830 Ma. The provenance of the Sickle Group is dominated by detritus shed from the Lynn Lake belt, but includes small amounts of older detritus, probably derived from crystalline rocks exposed in the hinterland of the orogen.

A Nd model age of ca. 2.1 Ga and a relatively juvenile, initial ε_{Nd} of approximately +3 for a metagreywacke from the Zed Lake area suggest source rocks that are dominantly less than 2.0 Ga but a lower proportion of pre-2.0 Ga source rocks than in the Sickle Group meta-arkose. Sensitive high-resolution ion microprobe (SHRIMP) U-Pb dating of zircons from the Zed Lake metagreywacke sample (Rayner, pers. comm., 2002) reveals that the bulk of the zircons analyzed (30 out of 33 grains) have ages around 1880 Ma. A number of zircon grains are younger than 1880 Ma, likely due to Pb loss, since they do not appear to be metamorphic. Only three zircons were found to have older ages (in the range 2300 to 2400 Ma). The dominant ca. 1880 Ma provenance suggests that the Zed Lake greywacke represents the deposition of detritus shed from the Wasekwan Group, which made up the northern Lynn Lake belt, and is older than the Burntwood Group metasedimentary rocks.

A Wasekwan Group turbiditic meta-arenite sample from the southeastern Lynn Lake belt has a juvenile Sm-Nd isotopic composition (T_{CR} Nd model age of ca 2.1 Ga corresponding to ε_{Nd} of +4 [mantle Sm-Nd isotopic composition] at ca. 1890 Ma). This is consistent with a predominantly ca. 1.89 Ga 'Wasekwan' volcanic provenance.

DISCUSSION

The relationship between the assembly of the volcanic tectonostratigraphy, at least four periods of synkinematic felsic magmatism between ca. 1876 and 1784 Ma, and two major periods of sedimentation describes a very dynamic, evolving tectonic regime (Fig. GS-19-4). Although many of the data reported here are considered preliminary, the emerging tectonic framework involves the accretion of two, possibly very different arcs to the Hearne Craton margin. The depleted arc-tholeiite and E-MORB volcanic geochemistry that dominates the rocks of the northern belt represents a possible intra-arc rift, whereas the arc-tholeiite and calc-alkaline volcanic geochemistry is typical of a juvenile island-arc setting (Zwanzig et al., 1999).

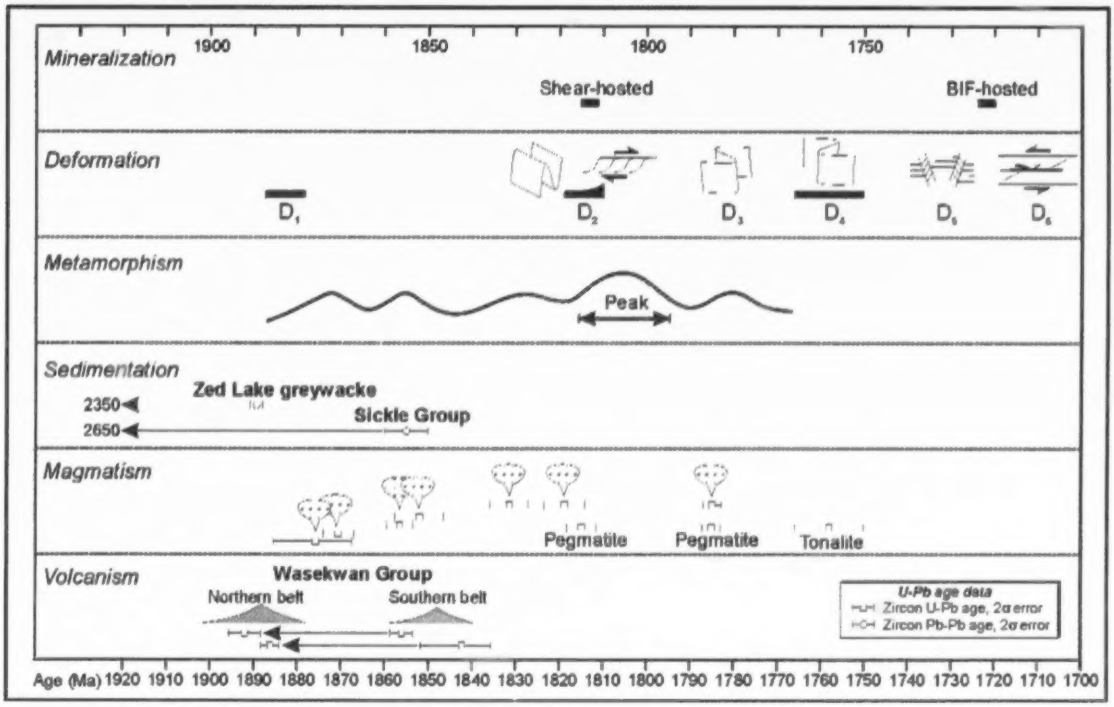


Figure GS-19-4. Time chart showing the relationship between volcanism, magmatism, sedimentation, deformation and metamorphism in the Lynn Lake greenstone belt. Abbreviation: BIF, banded iron formation.

The most significant aspect of the new data is the potential complexity involved in the assembly of the southern Lynn Lake belt. Contact relationships between the volcanic rocks and the Pool Lake suite suggest the presence of older (ca. 1890 Ma) volcanic rocks. However, U-Pb dating of the southern belt has yet to yield ages older than ca. 1855 Ma. The structural intercalation of MORB-like basaltic rocks of the Granville Lake Structural Zone in the western portion of the southern belt (Zwanzig, 2000) and transitional E-MORB basaltic rocks along the southern margin of the belt in the Wilmot Lake area suggest that the southern belt may represent a tectonic collage, assembled prior to or during accretion to the Hearne margin. This presumably occurred after ca. 1850 Ma, the youngest age of felsic volcanism in the southern belt.

The post-assembly history of the greenstone belt correlates well with the tectonic model for the northern Trans-Hudson Orogen proposed by Maxeiner et al. (2001). The focus of continued research is directed at unravelling the early history of the assembly of the volcanic tectonostratigraphy and the magmatic history of the Lynn Lake greenstone belt. This will enable the correlation of lithotectonic domains across the northern Trans-Hudson Orogen.

CONCLUSIONS

Continuing structural analysis, Sm-Nd isotopic studies and U-Pb geochronological studies of the Lynn Lake greenstone belt decipher a complex tectonic history documenting the assembly of an intricate tectonostratigraphy, comprising juvenile and contaminated volcanic-arc rocks. The northern Lynn Lake belt is mainly composed of weakly contaminated tholeiitic rocks deposited ca. 1886 to 1892 Ma, whereas the southern belt consists, in part, of juvenile tholeiitic and calc-alkaline rocks, some of which were probably deposited ca. 1856 to 1842 Ma. The main volcanic tectonostratigraphy was assembled during D_1, prior to the emplacement of ca. 1875, 1857 and 1830 Ma successor plutonic rocks, and prior to the deposition of fluvial-alluvial conglomerate and arkose along the southern margin of the greenstone belt.

The Lynn Lake greenstone belt experienced intense D_2 deformation that resulted in east-west transposition and the development of dextral transpressional shear zones at ca. 1819 Ma. Development of D_2 shear zones is penetrative throughout the greenstone belt, with the delineation of several major D_2 shear zones in the western portion of the greenstone belt. The D_2 major deformation is also responsible for the development of shear zone–hosted gold mineralization, which slightly predates the peak of regional metamorphism, estimated at ca. 1814 Ma. Accordingly, gold mineralization formed during prograde metamorphic conditions.

ACKNOWLEDGMENTS

The authors thank Jennifer Kavalench and Jennifer Greville for their enthusiastic assistance. David Corrigan is thanked for sharing his experiences and data throughout the evolution of this project. Paul Pawliw and Michael Gareau of Black Hawk Mining Inc. are thanked for their continued support of MGS research in the Lynn Lake belt. The review by Herman Zwanzig greatly improved the manuscript.

REFERENCES

Ansdell, K.M., Corrigan, D., Stern, R. and Maxeiner, R. 1999: SHRIMP U-Pb geochronology of complex zircons from Reindeer Lake, Saskatchewan: implications for timing of sedimentation and metamorphism in the northwestern Trans-Hudson Orogen; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Abstracts, v. 24, p. 3.

Baldwin, D.A. 1983: Stratigraphic studies of felsic volcanic rocks associated with mineral occurrences in the Lynn Lake area, Manitoba; *in* Report of Field Activities 1983, Manitoba Department of Energy and Mines, Mineral Resources Division, p. 88–93.

Baldwin, D.A., Syme, E.C., Zwanzig, H.V., Gordon, T.M., Hunt, P.A. and Stevens, R.P. 1987: U-Pb zircon ages from the Lynn Lake and Rusty Lake metavolcanic belts, Manitoba: two ages of Proterozoic magmatism; Canadian Journal of Earth Sciences, v. 24, p. 1053–1063.

Bateman, J.D. 1945: McVeigh Lake area, Manitoba; Geological Survey of Canada, Paper 45-14, 34 p.

Beaumont-Smith, C.J. 2000: Structural analysis of the Johnson Shear Zone in the Gemmell Lake–Dunphy Lakes area, Lynn Lake greenstone belt (parts of NTS 64C/11, /12); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 57–63.

Beaumont-Smith, C.J. and Edwards, C.D. 2000: Detailed structural analysis of the Johnson Shear Zone in the west Gemmell Lake area (NTS 64C/11); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 64–67.

Beaumont-Smith, C.J. and Rogge, D.M. 1999: Preliminary structural analysis and gold metallogeny of the Johnson Shear Zone, Lynn Lake greenstone belt (parts of NTS 64C/10, 11, 15); *in* Report of Activities 1999, Manitoba Energy and Mines, Geological Services, p. 61–66.

Beaumont-Smith, C.J., Anderson, S.D. and Böhm, Ch.O. 2001: Structural analysis and investigations of shear-hosted gold mineralization in the southern Lynn Lake greenstone belt (parts of NTS 64C/11, /12, /15, /16); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 67–75.

Fedikow, M.A.F. and Gale, G.H. 1982: Mineral deposit studies in the Lynn Lake area; *in* Report of Field Activities 1982, Manitoba Department of Energy and Mines, Mineral Resources Division, p. 44–54.

Gilbert, H.P., Syme, E.C. and Zwanzig, H.V. 1980: Geology of the metavolcanic and volcaniclastic metasedimentary rocks in the Lynn Lake area; Manitoba Energy and Mines, Geological Services, Geological Paper GP80-1, 118 p.

Goldstein, S.L., O'Nions, R.K. and Hamilton, P.J. 1984: A Sm-Nd study of atmospheric dusts and particulates from major river systems; Earth and Planetary Sciences Letters, v. 70, p. 221–236.

Hoffman, P.F. 1990: Subdivisions of the Churchill Province and extent of the Trans-Hudson Orogen; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 15–39.

Jones, L.R., Beaumont-Smith, C.J and Lafrance B. 2000: Preliminary structural and gold metallogenic studies at the Burnt Timber mine and surrounding area, Lynn Lake greenstone belt (NTS 64C/10); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 68–73.

Lewry, J.F. and Collerson, K.D. 1990: The Trans-Hudson Orogen: extent, subdivisions and problems; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 1–14.

Lin, S., Jaing, D. and Williams, P.F. 1998: Transpression (or transtension) zones of triclinic symmetry: natural example and theoretical modelling; *in* Continental Transpressional or Transtensional Tectonics, R.E. Holdsworth, R.A. Strachan and J.F. Dewey (ed.), Geological Society, London, Special Publication 135, p. 41–57.

Lucas, S.B., Stern, R.A., Syme, E.C., Reilly, B.A., and Thomas, D.J. 1996: Intraoceanic tectonics and the development of continental crust: 1.92–1.84 Ga evolution of the Flin Flon Belt, Canada; GSA Bulletin, v. 108, p. 602–629.

Ma, G. and Beaumont-Smith, C.J. 2001: Stratigraphic and structural mapping of the Agassiz Metallotect near Lynn Lake, Lynn Lake greenstone belt (parts of NTS 64C/14, /15); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 86–93.

Ma, G., Beaumont-Smith, C.J. and Lentz, D.R. 2000: Preliminary structural analysis of the Agassiz Metallotect near the MacLellan and Dot Lake gold deposits, Lynn Lake greenstone belt (parts of NTS 64C/14, /15); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 51–56.

Manitoba Energy and Mines 1986: Bedrock Geology Compilation Map Series, Granville Lake, NTS 64C, scale 1:250 000.

Maxeiner, R.O., Corrigan, D., Harper, C.T., MacDougall, D.G. and Ansdell, K.M. 2001: Lithogeochemistry, economic potential and plate tectonic evolution of the 'LaRonge–Lynn Lake Bridge', Trans Hudson Orogen; *in* Summary of Investigations 2001, Volume 2, Sasketchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 2001-4.2, p. 87–110.

Milligan, G.C. 1960: Geology of the Lynn Lake district; Manitoba Department of Mines and Natural Resources, Mines Branch Publication 57-1, 317 p.

Norman, G.W.H. 1933: Granville Lake district, northern Manitoba; Geological Survey of Canada, Summary Report, Part C, p. 23–41.

Peck, D.C. and Eastwood, A.M. 1997: Geochemical and structural analysis of gold mineralization at the Burnt Timber mine, Lynn Lake (NTS 64C/15); *in* Report of Activities, 1997, Manitoba Energy and Mines, Geological Services, p. 50–60.

Peck, D.C., Lin, S., Atkin, K. and Eastwood, A.M. 1998: Reconnaissance structural studies of the Au metallotects in the Lynn Lake greenstone belt (parts of NTS 64C/10, 11, 15); *in* Report of Activities, 1998, Manitoba Energy and Mines, Geological Services, p. 69–74.

Rogge, D.M. 2002: Application of data fusion for mineralization potential modeling, Lynn Lake greenstone belt, Manitoba, Canada; M.Sc. thesis, University of Manitoba Winnipeg, Manitoba.

Rogge, D.M., Halden, N.M. and Beamont-Smith, C.J. 2000: Mineralization potential mapping: a data fusion analysis; *in* Report of Activities 2000, Manitoba Industry Trade and Mines, Manitoba Geological Survey, p. 82–90.

Stauffer, M.R. 1984: Manikewan: an Early Proterozoic ocean in central Canada, its igneous history and orogenic closure; Precambrian Research, v. 25, p. 257–281.

Turek, A., Woodhead, J. and Zwanzig, H.V. 2000: U-Pb age of the gabbro and other plutons at Lynn Lake (parts of NTS 64C); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 97–104.

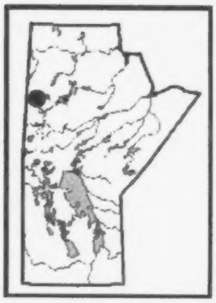
Whalen, J.B., Syme, E.C. and Stern, R.A. 1999: Geochemical and Nd isotopic evolution of Paleoproterozoic arc-type granitoid magmatism in the Flin Flon Belt, Trans-Hudson Orogen, Canada; *in* NATMAP Shield Margin Project, Volume 1, S.B. Lucas (ed.), Canadian Journal of Earth Sciences, v. 36, no. 2, p. 227–250.

Zwanzig, H.V. 2000: Geochemistry and tectonic framework of the Kisseynew Domain–Lynn Lake belt boundary (part of NTS 64P/13); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 91–96.

Zwanzig, H.V., Syme, E.C. and Gilbert, H.P. 1999: Updated trace element geochemistry of the ca. 1.9 Ga metavolcanic rocks in the Paleoproterozoic Lynn Lake belt; Manitoba Industry, Trade and Mines, Geological Services, Open File Report 99-13, 46 p. plus accompanying map and diskette.

GS-20 STRUCTURE AND STRATIGRAPHY IN THE AGASSIZ METALLOTECT, LYNN LAKE GREENSTONE BELT (NTS 64C14 AND 64C15), MANITOBA

by A.F. Park[1], C.J. Beaumont-Smith and D.R. Lentz[1]



Park, A.F., Beaumont-Smith, C.J. and Lentz, D.R. 2002: Structure and stratigraphy in the Agassiz Metallotect, Lynn Lake greenstone belt (NTS 64C14 and 64C15), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 171-186.

SUMMARY

Detailed structural analysis of the Agassiz Metallotect in the MacLellan mine area demonstrates that the distribution of the metallotect stratigraphy is a function of D_2 transposition, producing a hybrid tectonite lacking primary lithological characteristics. Locally, D_2 low-strain domains preserve a coherent stratigraphy. The structural geometry of the metallotect is the result of intense noncoaxial D_2 deformation, which produced isoclinal to rootless F_2 folds with a dominant Z-asymmetry and strongly curvilinear hinges. The overall F_2 fold geometry is a shallow plunging sheath, which overprinted shallow dipping (recumbent), isoclinal F_1 folds. The emplacement of gold mineralization and associated alteration appears to be lithology sensitive, with less competent rock types favoured.

GEOLOGICAL BACKGROUND

The Lynn Lake greenstone belt of northern Manitoba (Bateman, 1945) is part of the early Proterozoic Trans-Hudson orogenic belt that crosses the exposed Canadian Shield from northern Quebec and Baffin Island, across Hudson Bay and through the northern and central parts of Manitoba and Saskatchewan (*see* Hoffman, 1990). The Lynn Lake greenstone belt is bounded to the north by the Southern Indian Domain, a mixed metasedimentary and plutonic domain flanked to the north and southeast by the voluminous Wathaman-Chipewyan Batholith. To the south, the Lynn Lake belt is bounded by the Kisseynew metasedimentary domain (Gilbert et al., 1980). Similar greenstone belts occur to the east (Rusty Lake belt) and to the west (La Ronge belt of Saskatchewan).

The supracrustal rocks that constitute the Lynn Lake greenstone belt form the Wasekwan Group, consisting of mafic to felsic volcanic and volcaniclastic rocks and minor mafic intrusions, including a group of metapicrite bodies. The Wasekwan Group is distributed in two east-trending belts, referred to as the northern and southern Lynn Lake belts. The greenstone belt is overlain by two younger supracrustal successions. Along the northern margin of the belt, the Wasekwan Group is overlain by the Ralph Lake conglomerate and Zed Lake greywacke, both containing detritus derived predominantly from the greenstone belt (N. Rainer, pers. comm., 2001). The southern margin of the belt is overlain by younger fluvial-alluvial sedimentary rocks that constitute the Sickle Group. Igneous rocks, from metagabbro to granitoid, intrude some or all the supracrustal sequences. The metagabbro and diorite include the host to the Lynn Lake Cu-Ni-Co deposit, mined between 1958 and 1976, and are probably the earliest intrusive rocks postdating deposition of the Wasekwan Group. Their relationship to the other supracrustal groups is ambiguous, but they are deformed and were probably emplaced early in the deformation history. The granitoid bodies are predominantly later, with some predating deposition of the Sickle Group and others intruding the Sickle Group.

This study has concentrated on the Agassiz Metallotect (Fedikow and Gale, 1982; Fedikow, 1983, 1986, 1992; Fedikow et al., 1986, 1991) between Lynn Lake and the MacLellan mine (Fig. GS-20-1). This Au-Ag metallotect is completely contained within the supracrustal rocks of the Wasekwan Group in the northern Lynn Lake greenstone belt, especially the various mafic and ultramafic volcanic rocks. The Farley Lake and MacLellan gold mines, which are located within the Agassiz Metallotect, exploited mineralization hosted by quartz veins and related alteration in the mafic and ultramafic volcanic rocks.

LITHOLOGICAL UNITS

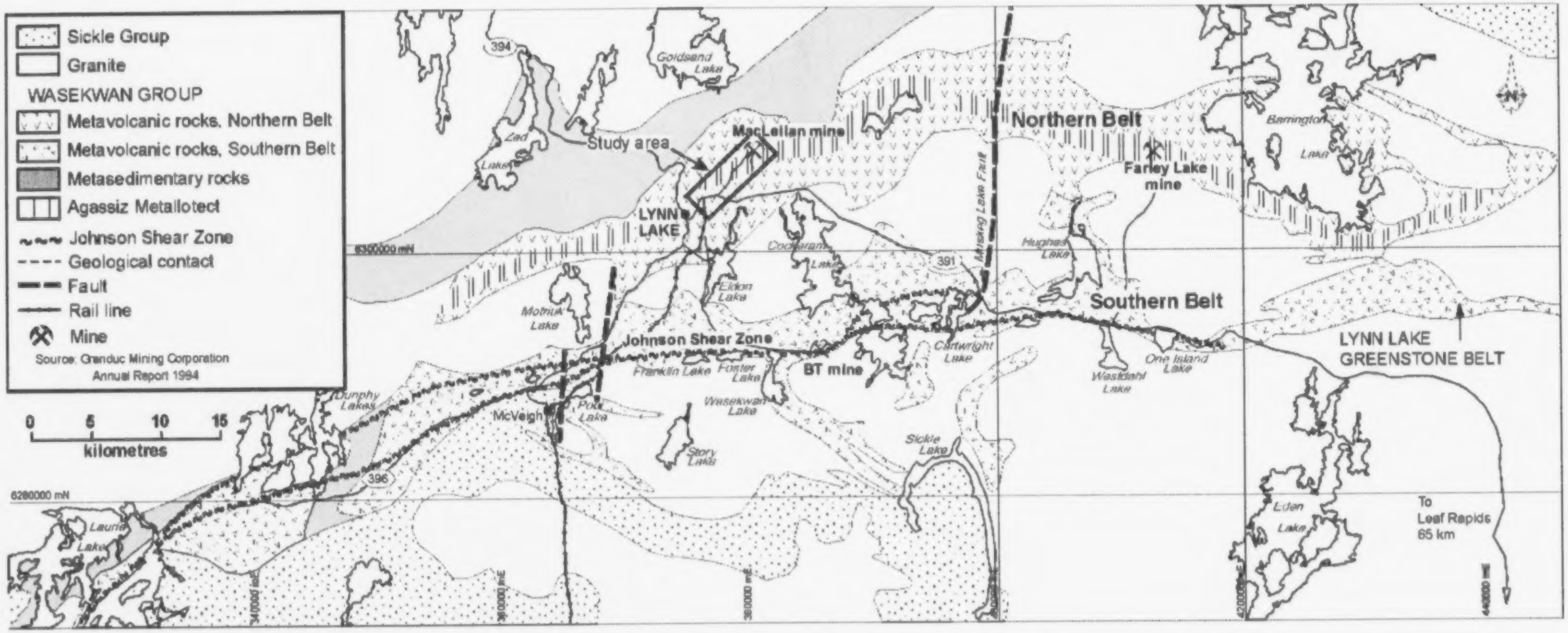
Eight lithological units are recognized at the 1:10 000 mapping scale of the Agassiz Metallotect in the MacLellan mine area (Fig. GS-20-2).

Metapicrite (unit 1)

These rocks are actinolite-talc-chlorite schist with variable amounts of biotite, magnetite-chromite and carbonate (mainly siderite), and are the equivalent of the 'high Mg-Cr-Ni' basalt of Gagnon (1991). They weather a very

---

[1] Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3


Sickle Group
Granite
WASEKWAN GROUP
Metavolcanic rocks, Northern Belt
Metavolcanic rocks, Southern Belt
Metasedimentary rocks
Agassiz Metallotect
Johnson Shear Zone
Geological contact
Fault
Rail line
Mine
0
5
10
15
kilometres
Study area
MacLellan mine
LYNN LAKE
Northern Belt
Farley Lake mine
Southern Belt
Johnson Shear Zone
BT mine
LYNN LAKE GREENSTONE BELT
Misking Lake Fault
To Leaf Rapids 65 km
Goldsand Lake
Zed Lake
Barrington Lake
Cockeram Lake
Eldon Lake
Hughes Lake
Motriuk Lake
Franklin Lake
Foster Lake
Cartwright Lake
Wasekwan Lake
Wasteahl Lake
One Island Lake
Sickle Lake
Story Lake
Pool Lake
McVeigh
Dunphy Lakes
Laurie Lake
Eden Lake
394
391
396
6300000 mN
6280000 mN
340000 mE
360000 mE
380000 mE
400000 mE
420000 mE
440000 mE
N

Source: Granduc Mining Corporation Annual Report 1994

Figure GS-20-1: General geology of the Lynn Lake greenstone belt, showing the location of the Agassiz Metallotect and the study area.

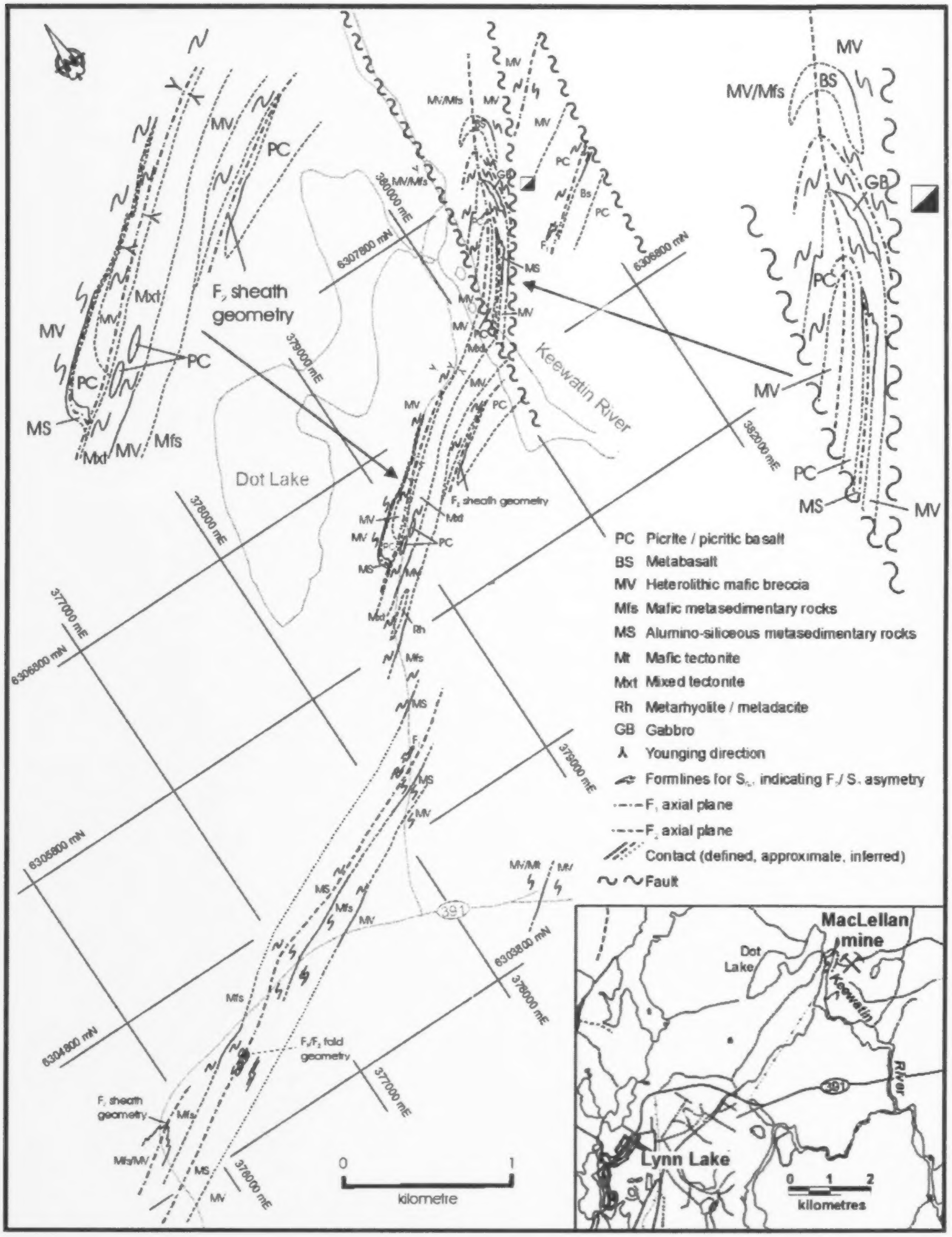

F$_2$ sheath geometry
MV
MV/Mfs
BS
GB
PC
Mxt
MS
Mfs
Mt
Rh
MV/Mt
Dot Lake
Keewatin River
380000 mE
379000 mE
378000 mE
377000 mE
382000 mE
6307800 mN
6306800 mN
6305800 mN
6304800 mN
6303800 mN
391
F$_1$/F$_2$ fold geometry
0
1
kilometre
PC Picrite / picritic basalt
BS Metabasalt
MV Heterolithic mafic breccia
Mfs Mafic metasedimentary rocks
MS Alumino-siliceous metasedimentary rocks
Mt Mafic tectonite
Mxt Mixed tectonite
Rh Metarhyolite / metadacite
GB Gabbro
Younging direction
Formlines for S$_{1-2}$ indicating F$_2$/S$_2$ asymetry
F$_1$ axial plane
F$_2$ axial plane
Contact (defined, approximate, inferred)
Fault
MacLellan mine
Dot Lake
Keewatin River
391
Lynn Lake
0 1 2
kilometres

Figure GS-20-2: Detailed geology of the Agassiz Metallotect between the town of Lynn Lake and the MacLellan mine.

distinctive 'forest green.' Pillow selvage relicts are locally recognized, but these rocks are tectonite in most localities. Amphibole and talc have reciprocal modal abundances, in that metapicrite at the MacLellan minesite is characterized by 40% or more coarse actinolitic hornblende and accessory talc, whereas 2 km to the southwest at the 'Rushed zone', it is talc-chlorite schist (up to 50% modal talc) with minor actinolite.

Metabasalt (unit 2)

Massive metabasalt has been altered to fine-grained amphibolite that weathers a distinctive dark grey to black. Both aphyric and plagioclase-phyric basalt are recognized, and pillow relicts survive. These rocks vary from moderate to well foliated, and are less common than previous studies suggest.

Heterolithic mafic breccia (unit 3)

This is a generally well-foliated amphibolite with abundant relicts of angular to subrounded clasts of aphyric basalt, plagioclase-phyric porphyritic basalt, mafic pillows and pillow fragments. The matrix commonly forms 30 to 50% of the rock, but locally grades up to 100% with outsized clasts absent. This matrix can be aphyric or plagioclase-phyric, and can be mistaken for massive metabasalt when clast poor. This clast-poor material sporadically preserves sedimentary structures, including erosive contacts of coarse, sand-size units on finer silt to mud, crossbedding and channel forms. Every variation from clast-rich, poorly structured units to clast-poor units exists, with many displaying characteristics of turbidity-current deposits.

Overall, this unit accounts for more than 60% of the outcrop exposures between Lynn Lake and the MacLellan mine, representing the southwest end of the Agassiz Metallotect (Fedikow, 1983). Identifying and making use of the way-up indicators present in the more mature mafic volcaniclastic turbidite units has revealed details of the F_1 and F_2 fold relationships previously not documented in this extensive unit.

Mafic metasedimentary rocks – para-amphibolite (unit 4)

Fine- to medium-grained mafic schist alternates with bands of amphibole-rich and amphibole-poor material on the centimetre to decimetre scale. The modal variants seen in this unit consist of variable amounts of garnet, biotite, epidote, plagioclase and chlorite. This lithology is gradational into the more turbiditic components of the heterolithic mafic breccia (unit 3).

Alumino-siliceous metasedimentary rocks (unit 5)

Fine- to medium-grained schist with garnet-amphibole-biotite-plagioclase and quartz shows banding on the centimetre scale. Modal variations in garnet-amphibole and quartz define the bands. This unit interlayers with the mafic metasedimentary rocks, and is locally rich in sulphide minerals, especially along its contacts with mafic metasedimentary rocks and the heterolithic mafic breccia.

Felsic porphyroblastic schist (unit 6)

These are coarsely banded feldspar-mica-quartz-amphibole rocks, with the banding created by modal variations in mica content. These units are generally thin (<5 m thick) but locally persistent along strike (up to 1 km in one case). They are interlayered with mafic metasedimentary rocks and alumino-siliceous metasedimentary rocks, with exposed contacts commonly being rich in sulphide minerals. They appear to represent felsic volcaniclastic rocks.

Massive felsic units / metarhyolite (unit 7)

These are of limited occurrence, only recorded at the MacLellan minesite in any abundance and sporadically to the southwest. They are, however, a major lithology to the south of the Agassiz Metallotect in the 'Lynn rhyolite'. They are fine-grained, aphyric or porphyritic, quartz-rich rocks with variable amounts of feldspar (this being the phenocryst/porphyroblast species) and white mica. No primary textures have been identified at the MacLellan minesite. Most bodies are tectonized and their relationships to other rocks are obscured, but primary intrusive contacts are preserved in metarhyolite sheets associated with the 'Rushed zone.'

Ferruginous metasedimentary rocks (unit 8)

Iron-rich metasedimentary rocks do not form mappable units, but consistently occur as distinctive elements of the mineralized zones throughout the metallotect. A quartz-rich, white mica schist with pyrrhotite-pyrite forms a discontinuous layer through the 'Rushed zone' and its extension to the northeast. Similar discontinuous layers occur in the K-2 zone. In both cases, the layer in question is less than 0.5 m thick and traceable for tens of metres, with boudinage being responsible for the discontinuous nature of the layer. A quartz-magnetite iron formation occurs within metasedimentary rocks of units 4 and 5 at the MacLellan mine. It is up to 0.3 m thick but cannot be traced continuously from these outcrops. A pyrrhotite-rich, graphitic black pelite has also been recorded at the MacLellan mine.

Interpretation of the heterolithic mafic breccia

This lithologically diverse unit makes up some 60% of the outcrop between the MacLellan mine and Lynn Lake. As the name implies, the most common rock type is a psephite, which is characterized by angular to subrounded clasts in a finer matrix (original matrix grain size is conjectural, as all of these mafic metasedimentary rocks are recrystallized to amphibolite). Clast size ranges up to boulder (>64 mm) but is more commonly cobble or pebble (Fig. GS-20-3a, b, c). Clast types are all mafic, consisting of aphyric and plagioclase-phyric metabasalt (both amygdaloidal and nonamygdaloidal varieties; Fig. GS-20-3a). Alteration, where present, is represented in the recrystallized material as an abundance of calc-silicate minerals (generally epidote, with some garnet and amphibole). Clasts may be either completely altered or only partly replaced (Fig. GS-20-3d, e), but this alteration terminates at the clast margins. Many clasts appear to be fragments of pillowed flows (Fig. GS-20-3c) or, more rarely, whole pillows, and recrystallized selvages or segments of such selvages are still recognizable.

Clast to matrix proportions vary considerably, from outcrops where only isolated clasts can be identified (in the absence of bedding, such outcrops have been mapped as massive basalt) to outcrops where clasts make up more than 75% of the rock. Even in the clast-dominated material, however, clast-supported breccia is quite rare. Most of the breccia is matrix supported.

The matrix itself shows considerable variation in appearance. Mostly, it is an aphyric, fine- to medium-grained amphibolite, but plagioclase porphyroblasts, possibly after primary grain-clasts, are locally abundant. Where bedding can be identified, grading is evident, from coarse sand-sized material downwards, possibly to material originally as fine-grained as silt (recrystallization precludes a conclusive determination).

Bedding (S_0, usually transposed as S_{0-1} or S_{0-1-2}) is best defined in the fine-grained, clast-poor parts of the heterolithic mafic breccia, and it is in this material that size grading and other way-up indicators are best defined. Crossbeds (Fig. GS-20-3f), channel forms, scours and erosive bases have all been identified, as well as possible rip-up clasts in one example. In these clast-poor units, plagioclase porphyroblasts are generally larger and more abundant in the coarser part of the graded unit, and are either sparsely developed or absent from the finer upper parts. When clasts are rare or absent, these graded units are on the order of a metre thick and are identical to the mafic metasedimentary rocks (para-amphibolite) that form independently mappable units throughout this part of the Lynn Lake belt. This equivalence is reinforced by the present of large breccia clasts near the base of larger graded units within the heterolithic mafic breccia, and the appearance of such units within the mafic metasedimentary rocks.

The morphological range of the bedded units within the heterolithic mafic breccia can be summarized as follows:

1.) **Clast-dominated units:** These show very poorly defined bedding, when they show bedding at all. Individual units are in excess of 3 m thick, and very little grading is evident throughout most of the thickness of these units. Where tops can be defined, a thin drape of sand-sized material is evident, but this is generally less than 10 cm thick. Bases of these units are erosive into underlying units. Clast-supported breccia may be present in the lower parts of these units but is not typical.

2.) **Crudely graded clast-rich units:** These are better organized than the clast-dominated units. Where full thickness can be seen, they are generally 1 to 2 m thick and have 40 to 50% fine-grained (i.e., sand size and finer) material present toward the top. Clast-dominated material is confined to the lower half. Bases are erosive into underlying units and the upper part may contain preserved crossbedding.

3.) **Graded clast-poor units:** These have the best preserved bedding and are generally less than 1 m thick. Where clasts are present, they are confined to the basal portion. Preserved bases are erosive into underlying units and the tops are fine grained. When these units are free of outsized clasts, they are identical to the graded units seen in the mafic metasedimentary rocks and are only differentiated in mapping when they are interlayers within the heterolithic mafic breccia.

It must be emphasized that this three-fold subdivision represents distinct points on a continuous spectrum, and all variations between types 1 and 3 can be found in outcrop. However, this range seems to represent a gradation from poorly organized massive units through material that becomes better organized (graded) as the outsized clasts diminish

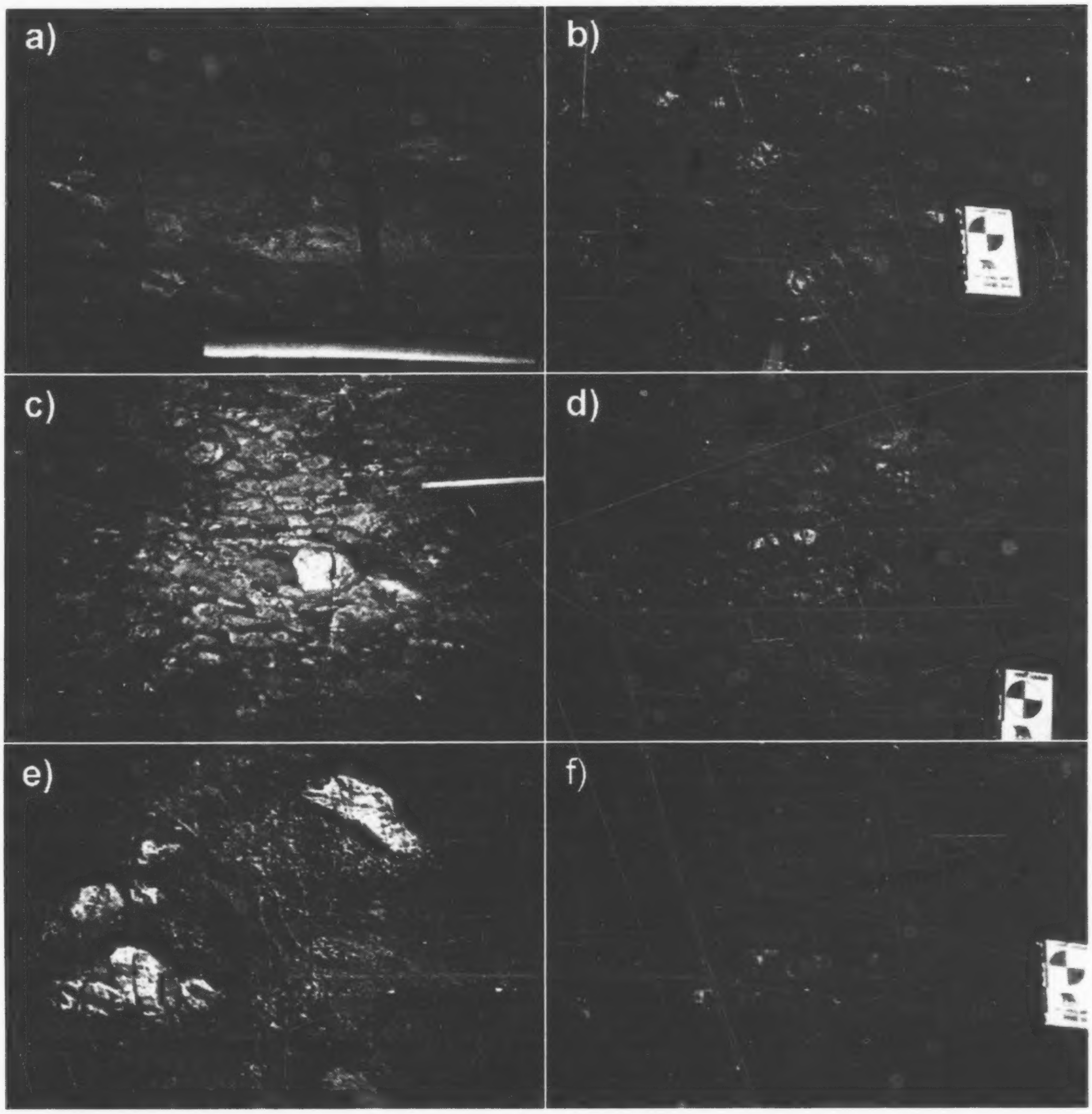


Figure GS-20-3: a) Heterolithic mafic breccia with matrix-supported clasts up to boulder size; both aphyric and porphyritic basalt clasts are present. b) Pebble- to cobble-size clasts in heterolithic breccia; scale on notebook is in centimetres, north toward the top. c) Mixed clast population in heterolithic mafic breccia, including aphyric and porphyritic basalt, and pillowed fragments; large clast in centre was silicified (note different competence) prior to deformation. d) Silicified, nonsilicified and partly silicified basalt clasts in heterolithic mafic breccia. e) Detail from Fig. GS-20-3d, showing partly silicified basalt clasts in heterolithic mafic breccia; silicification is cut off by the clast margin, and therefore predated clast formation. f) Fine-grained unit in heterolithic mafic breccia displaying relict crossbedding; way-up indicates top is toward top of photo (south).

in abundance. This range represents a facies transition from massive debris flows to mafic volcaniclastic turbidites. The debris is generally well mixed. Single units, in the range between types 1 and 2, can therefore contain altered and unaltered, aphyric and porphyritic material, pillows, pillow debris and clasts that are neither. The material being transported consists of a mixture of aphyric and porphyritic mafic flow debris, pillows and pillow fragments. Among the pillow fragments, both complete and incomplete selvages are seen, implying that some of the debris was hyaloclastite. How much of the finer grained (sand size and smaller) was originally tuff cannot be ascertained. Hyaloclastic debris does not seem to form independent units; it is always mixed in with the other clast types.

The interpretation offered here is that the heterolithic mafic breccia is cogenetic with the mafic metasedimentary rocks, and the contrast between them represents a proximal-distal facies relationship. The poorly organized, clast-dominated types are debris flows, which laterally range into better graded turbidites, substantial accumulations of which (minus the outsized clasts) form the mappable mafic metasedimentary units (unit 4). If this interpretation of the heterolithic mafic breccia is appropriate, then it raises a number of important points. Firstly, of the massive basalt and metapicrite units found within the outcrop of the heterolithic mafic breccia (i.e., all those identified between Lynn Lake and the MacLellan mine), only a small number preserve intrusive relationships with the breccia and are clearly hypabyssal intrusions. Even those outcrops that retain pillow selvages (both basalt and picrite pillows are seen at the MacLellan minesite) cannot be unambiguously defined as autochthonous. Recent examples of debris flows from the flanks of island volcanoes are known to contain slumped blocks of massive volcanic material in the 0.5 to 10 km size range (e.g. North Kona landslide, Hawaii; *see* Moore et al., 1995). Secondly, geochemical studies of these volcanic rocks must acknowledge their essentially sedimentary nature. Although volcanic debris may still yield geochemical signatures identifying characteristics of their source, individual debris flow units may contain debris from more than one eruptive centre, or one stage in the evolution of the volcanic edifice. Such sampling should be confined to the coarser clasts, as the finer matrix is more likely to be of mixed provenance.

TECTONO-LITHOSTRATIGRAPHY

Given the degree of deformation and transposition parallel to the S_2 foliation throughout the Agassiz Metallotect, any 'stratigraphy' must be regarded as a preliminary scheme for the purposes of regional mapping. Recognition of way-up criteria in the heterolithic mafic breccia has, however, revealed some relationships of local significance.

Way-up indicators in the heterolithic mafic breccia near contacts with various metasedimentary units, in areas where the D_2 structure opens out in low-strain enclaves, show metasedimentary rocks (units 4 and 5) consistently above breccia. Where both types of metasediment are present, type 4 is always beneath type 5. Mafic breccia is also inter-layered with mafic metasedimentary rocks. This is consistent with the mafic metasedimentary rocks being largely or partially a distal facies variation of the heterolithic mafic breccia.

The massive basalt and picrite are either flows or hypabyssal intrusions, or possibly both, given their continuity over tens to hundreds of metres. In those areas where they occur among the heterolithic mafic breccia in D_2 low-strain enclaves, way-up criteria indicate homoclinal panels where both rock types occur within mafic breccia. Most contacts are tectonized, even in low-strain enclaves, but the presence of pillow relicts in both basalt and picrite indicates that some bodies are flows. Caution is necessary, however, in interpreting their stratigraphic relationship to the breccia. Given the interpretation of these breccia units as submarine debris flows slumped from hyaloclastic deltas marginal to volcanic islands, there is the possibility that the basalt and picrite could also be megaclasts.

STRUCTURAL HISTORY

The sequential development of structural elements in the rocks of the Agassiz Metallotect has been discussed by Gilbert et al. (1980) and Beaumont-Smith and Rogge (1999). The reader is also referred to work by Ma et al. (2000), Beaumont-Smith (2000), Beaumont-Smith and Edwards (2000), Jones et al. (2000), Beaumont-Smith et al. (2000), Beaumont-Smith et al. (2001), Anderson and Beaumont-Smith (2001) and Ma and Beaumont-Smith (2001). At least five generations of folds and foliations and their related lineations have been identified, plus faults and fractures. Four generations of these elements have been recognized between Lynn Lake and the MacLellan mine (Fig. GS-20-2).

Structure from Lynn Lake to the MacLellan mine is dominated by D_2 structures and the associated high strain and transposition. The D_2 structures are the primary influence on outcrop pattern–defining lithological packages contained within and lying parallel to the Johnson Shear Zone (Bateman, 1945). The entire outcrop of the 'north belt' of the Lynn Lake greenstone belt between Lynn Lake and the MacLellan mine (i.e., the Agassiz Metallotect) is contained within D_2 structures, and all earlier structural elements are either restricted to low-strain enclaves, seen at scales ranging from less than 1 m on outcrop to zones more than 0.5 km in strike length and approximately 200 m across strike. Most pre-D_2 features are transposed into the S_2 foliation (Ma et al., 2000; Ma and Beaumont-Smith, 2001).

Deformation D_1

The F_1 folds and an axial-planar S_1 foliation are preserved in low-strain enclaves forming complex interference patterns with F_2. The S_1 foliation is a spaced (0.5–2 mm), differentiated foliation defined by modal variations in most rock types, although weakest in the heterolithic mafic breccia. It is always close to, if not actually parallel to, S_0 (primary layering or bedding).

The F_1 folds are isoclinal and generally preserved as rootless, intrafolial relicts transposed in S_2. This makes determination of their original form difficult. Where the S_{0-1}enveloping surface is visible, however, it is commonly within 20° of horizontal, except where F_2 fold hinges are strongly curvilinear. This characteristic, and the general low angle between S_0 and S_1, implies that F_1 folds were isoclinal with shallow-dipping or horizontal axial planes prior to D_2. Locally well-preserved F_1-F_2 interference patterns are consistent with this. Although F_1 folds now have distinctly curvilinear hinges, it is not possible to determine, through the D_2 overprint, whether they were originally sheath folds.

Deformation D_2

These elements dominate the Lynn Lake–MacLellan mine transect, and the progressive, noncoaxial nature of the D_2 structures can be demonstrated at a number of locations on several scales (Fig. GS-20-2, GS-20-4).

The S_2 foliation has a heterogeneous expression with varying degrees of transposition. Some of the best preserved evidence for the development of this fabric is seen in the metapicrite. In low-strain enclaves within metapicrite boudins, S_2 is a well-spaced foliation (1–4 cm), initiated as dark, discontinuous septa on asymmetric Z- and S-microfolds. As strain increases, the S_2 septa become more continuous, and the intervening microlithons narrower (0.5–1 cm) in a well-defined crenulation. Eventually, the form of F_2 microfolds is lost in an S_2 phyllonite containing isolated lithons with S_1 relicts, some of which become S-surfaces in a C-S foliation. These relicts are eventually obscured by S_2-generation C′-shear bands.

The F_2 folds generally have axes plunging between 5° and 40° to the northeast, consistent with the general trend of the L^1_2 lineation (intersection of S_1 and S_2). On the outcrop scale, however, both F_2 axes and this axis-parallel lineation locally define tightly curvilinear fold hinges that are true sheaths (showing rotation through 300° in the axial plane). This pattern is not repeated at larger scales. A second asymmetry is also apparent. Shear sense on S_2 for F_2 minor folds, C-S fabrics, C′-plane shear bands and extension-shortening geometries for deformed veins is predominantly right-lateral (dextral) on horizontal surfaces. Other geometries, such as M- and W-F_2 minor folds, S- and left-lateral shear-sense indicators are few and always associated with visible F_2 closures and low-strain enclaves. On the largest scale, this suggests that F_2 folds are strongly asymmetric structures dominated by their right-lateral limbs and the northeast-plunging sectors of their hinges (Fig. GS-20-2, GS-20-4). They have a sheath geometry, but the complementary left-lateral limbs and southwest-plunging hinge segments are only preserved in low-strain zones (Fig. GS-20-4).

Some of this ambiguity could be clarified if an L_2 stretching lineation could be identified more widely. There is no shortage of lineations on the S_2 foliation, but most of them are intersection lineations or mineral growths following differentiation along these intersections. Aside from the ubiquitous and locally dominant S_4 crenulation of S_2, the following intersection lineations have been noted:

L^1_2: the S_1-S_2 intersection lineation, commonly plunging 5° to 40° northeast, locally defining sheath closures

$L^{c\text{-}s}_2$: the intersection of S-planes with C-planes within S_2 and locally developed from the L^1_2 intersection; it is usually steeply dipping (>70°) to down-dip on S_2

$L^{s\text{-}b}_2$: the intersection of C′-plane shear bands with S_2 C-planes; generally steep (>70°) to down-dip on S_2

Less commonly, an L^s_2 stretching lineation is preserved as a mineral growth with length-parallel pull-apart (usually in coarse amphibole) or as a prolate form to the deformed clasts in the heterolithic mafic breccia. These examples are shallow plunging (<30°) or subhorizontal. This is consistent with an overall sheath geometry for the F_2 folds, but does not demonstrate it.

Deformation D_3

These are structures recognized regionally, including a spaced cleavage (S_3). Too few examples have been noted in the Lynn Lake–MacLellan mine transect to make any conclusions about its overall geometry or significance.

Deformation D_4

These structural elements overprint those of D_2 throughout the area. The F_4 folds are open to tight structures with steeply plunging axes and vertical or near-vertical axial planes. Fold asymmetry on all scales is predominantly right-lateral. The S_4 is a spaced fracture or spaced crenulation cleavage (0.5–2 cm) overprinting S_2 and is locally very strong (obliterating or partly obscuring L_2 lineations). Fractures and small-scale shears parallel to S_4 often carry quartz veins and are locally defined by thin pseudotachylite veinlets. A large-scale F_4 fold, partly modified by later faults, is responsible for the dramatic change in strike of S_2 and the orientation of F_2 axial planes at the MacLellan minesite. This is the only example on this scale of F_4 structure in the Lynn Lake area.

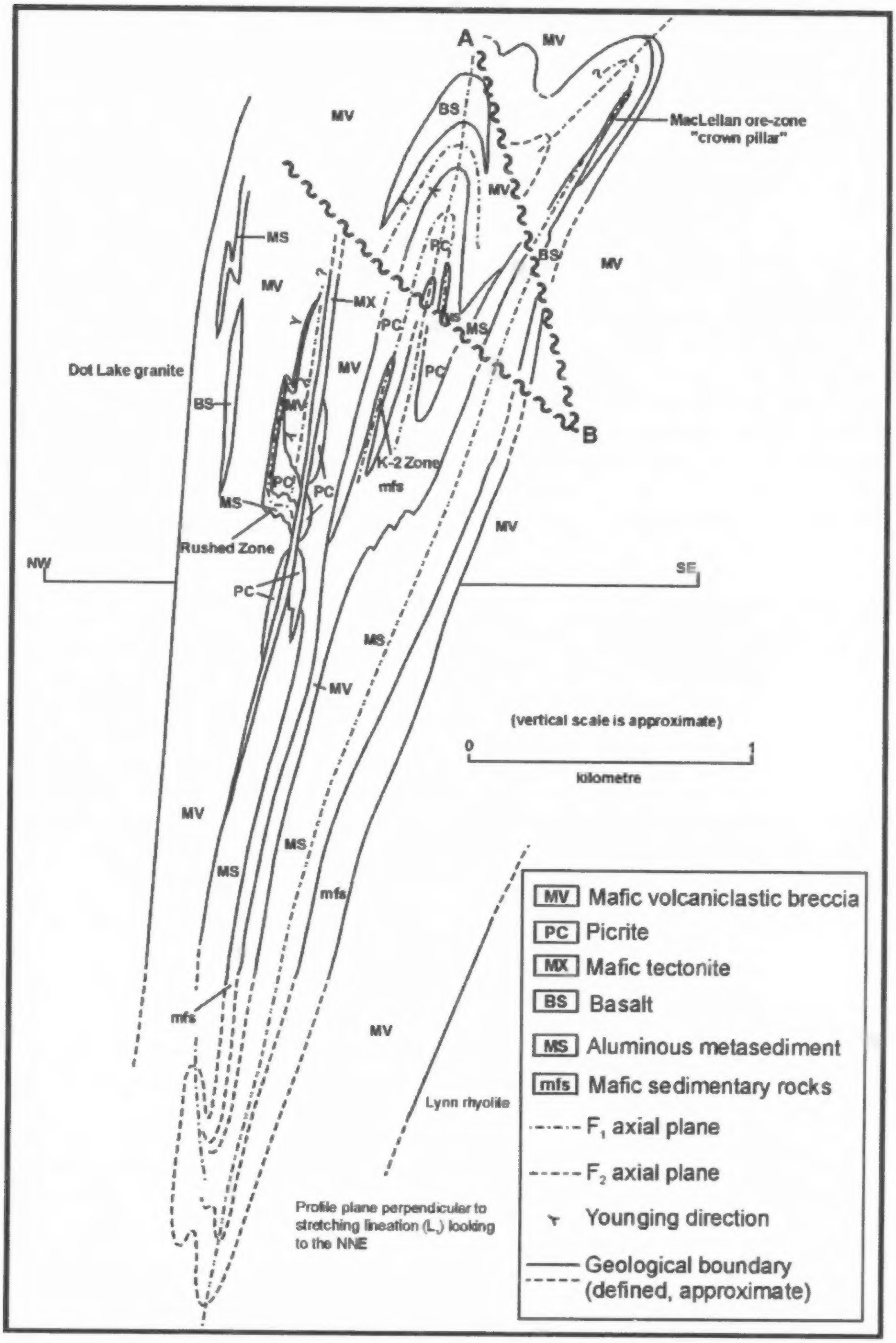

A
B
MV
BS
MacLellan ore-zone "crown pillar"
MS
PC
MX
Dot Lake granite
K-2 Zone
mfs
Rushed Zone
NW
SE
(vertical scale is approximate)
0
1
kilometre
Lynn rhyolite
Profile plane perpendicular to stretching lineation (L2) looking to the NNE
MV Mafic volcaniclastic breccia
PC Picrite
MX Mafic tectonite
BS Basalt
MS Aluminous metasediment
mfs Mafic sedimentary rocks
F1 axial plane
F2 axial plane
Younging direction
Geological boundary (defined, approximate)

Figure GS-20-4: Structural cross-section through the Agassiz Metallotect between Lynn Lake and the MacLellan mine. Out-of-section details are projected into the profile plane parallel to the L_2 stretching lineation. The profile plane is oriented northwest-southeast about 2 km southwest of the MacLellan mine. Looking north down the plunge of most F_2 folds.

Late faults and fractures

At least three faults, vertical structures trending north to north-northeast, occur near the MacLellan mine. One of these runs parallel to the Keewatin River south of Dot Lake and has the largest displacement. At least two faults that are splays of this structure cross the minesite. No other faults affect the outcrop pattern to this extent. Although the faults themselves are not exposed, outcrops close to their presumed location carry abundant pseudotachylite veins. Indeed, some of these outcrops are effectively pseudotachylite breccia.

LARGE-SCALE STRUCTURE

Based on detailed observations of the vergence of F_2 minor folds, the asymmetry of S_1, S_{0-1} and S_2 relationships, kinematic indicators of shear sense related to S_1 and S_2, and facing of S_0 and S_{0-1} on S_2, some aspects of regional structure in the Agassiz Metallotect can be resolved from this study. From Lynn Lake to the MacLellan mine, the structure is dominated by a large F_2 fold, the core of which is marked by vergence change across a belt of metasedimentary rocks (Fig. GS-20-2). This structure can be traced up to the Keewatin River immediately west of the mine, where it is offset by the fault lying parallel to the river. The continuation across the fault is more speculative, but the interpretation favoured here is that the F_2 closure seen immediately east of the Keewatin River is a mesoscale parasitic F_2 fold, while the main closure runs into the ore zone at the mine itself (Fig. GS-20-2). However, projection of these structures across the second fault (A-B on Fig. GS-20-4) is very provisional. There are schlieren of metasedimentary rocks in the MacLellan orezone, but this enclave could also be an F_1 closure with an F_2 overprint. Extant data cannot resolve this, but small-scale F_1 structures refolded by F_2 are present here.

Viewed in cross-section, the F_2 folds close both up and down in the plane of section because this profile plane is perpendicular to the stretching lineation L_s and they are large-scale sheaths (Fig. GS-20-4). That this is not an F_1-F_2 interference pattern is demonstrated by the few localities where F_1 folds can be traced out. The 'Rushed zone', together with its continuation along the mine road, is one such location. The metasediment enclave hosting the mineralization is an F_1 closure, with sedimentary top directions pointing into the enclave from both sides. When this F_1 fold is traced along the larger F_2 limb, the F_2 minor folds change from S- to Z-asymmetry, whereas the plunge of the minor folds does not change. Sheath geometries can be demonstrated in a similar fashion at the K-2 zone, where F_2 minor folds display strongly curvilinear hinge lines on a single axial plane, and in the road cuts 300 m north of Lynn Lake, where the same features occur and a single stretching lineation (L_s) direction can be observed.

Transposition is a common characteristic throughout the Agassiz Metallotect, but one zone of intense transposition is large enough to be a mappable unit and can be traced for at least 3 km. This is the 'mixed tectonite' unit shown on Figure GS-20-2. The F_2 sheath fold that includes the Rushed zone is related to this structure (it forms the southern limb of the fold). This does not represent a major structural break; it is just an extreme development of the common, stronger transposition on the dextral limbs. Although the F_2 folds are sheath folds, there is a very strong asymmetry, where the longer limbs have dextral shear sense, and the opposing limbs with sinistral shear sense tend to be short and often sheared out. It is this bias that gives the entire zone a predominant right-lateral strike-slip shear sense. Another strong bias comes from the preserved closures. The sheath tips cover relatively small areas. Most outcrop lies on the upward or downward closures away from the tip. As with the strong asymmetric limbs, the northeast-plunging closures are more common than those plunging southwest.

Detailed locality maps

Four locations were mapped at very detailed scales (outcrops gridded at 10 m), as large as 1:200, because they were mineralized and/or showed especially important field relationships between lithological units, veins and alteration, or meso- to macroscopic structure.

1.) MacLellan minesite, 300 m southwest of head frame (Fig. GS-20-5)

Stripped and cleaned outcrops at the MacLellan minesite display relationships between lithostratigraphy and F_2 folds involving iron formation, mafic metasedimentary rocks, alumino-siliceous metasedimentary rocks, metapicrite and metarhyolite. The iron formation is attenuated and discontinuous around an isoclinal fold hinge. The S_1 and S_2 foliations here are nearly parallel and are both parallel to the axial plane in the fold hinge. For this reason, it is impossible to determine whether this is an F_1 or F_2 fold. It may be either an F_2 fold in the closure of the larger structure mapped in the western part of the minesite, or an F_1 fold in the limb of this larger structure.

Metapicrite, interlayered with heterolithic mafic breccia, grades to the southeast into mafic tectonite, with relicts of both rock types observed and with pseudotachylite and cataclasite of two generations evident. The early generation

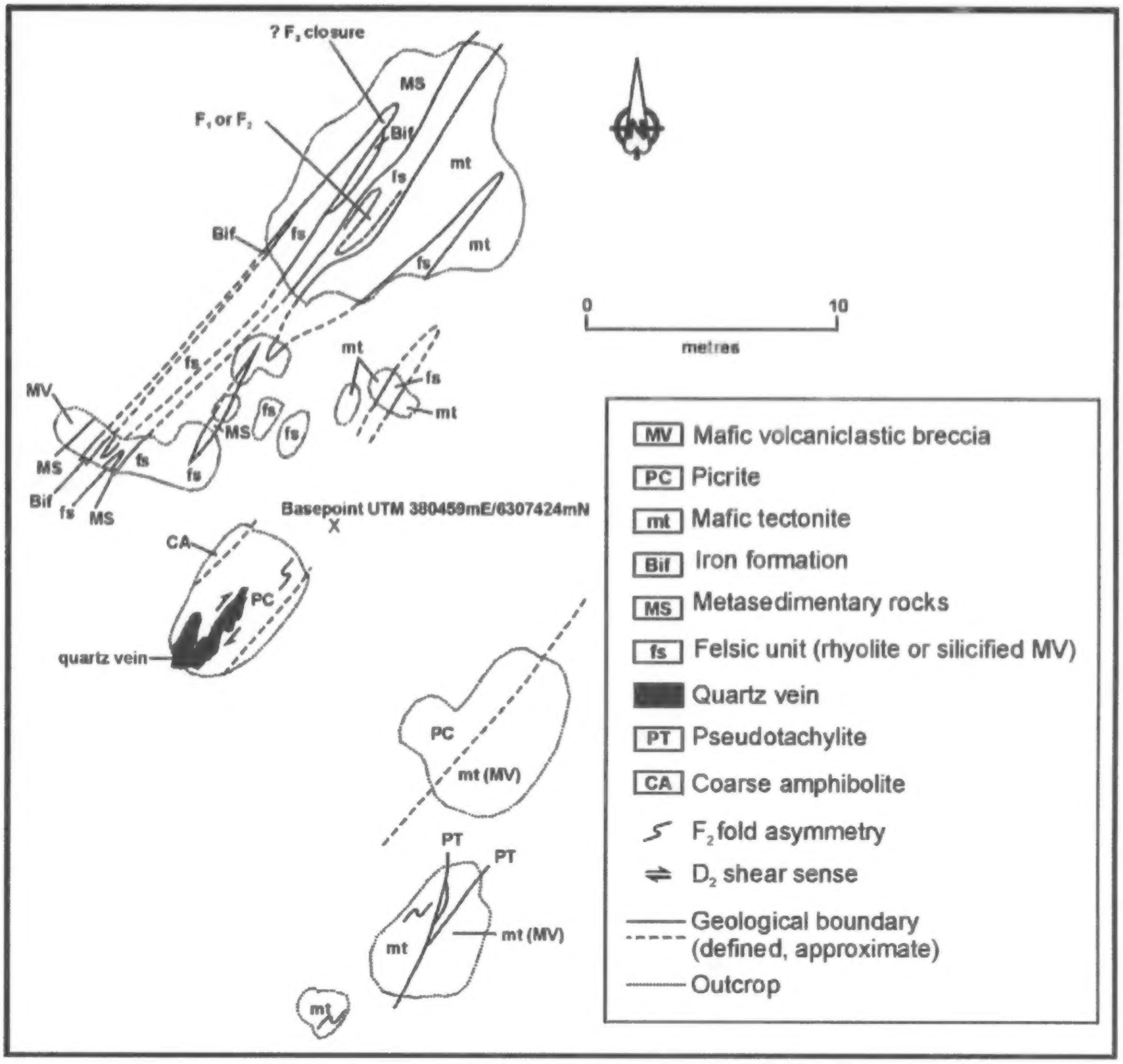

? F_3 closure
F_1 or F_2
MS
Bif
fs
mt
Bif
fs
mt
fs
0
10
metres
mt
fs
fs
mt
MV
MS
fs
fs
MS
fs
Bif
fs
MS
MS
Basepoint UTM 380459mE/6307424mN
X
CA
PC
quartz vein
PC
mt (MV)
PT
PT
mt
mt (MV)
mt
MV Mafic volcaniclastic breccia
PC Picrite
mt Mafic tectonite
Bif Iron formation
MS Metasedimentary rocks
fs Felsic unit (rhyolite or silicified MV)
Quartz vein
PT Pseudotachylite
CA Coarse amphibolite
F_2 fold asymmetry
D_2 shear sense
Geological boundary (defined, approximate)
Outcrop

Figure GS-20-5: Detailed outcrop map of cleaned exposures southwest of the MacLellan mine headframe.

is predominantly cataclasite developed parallel to the S_2 foliation, and is widely chloritized and crenulated by S_4. The later phase, with well-preserved pseudotachylite (chilled margins and intrusive veinlets), is partly discordant to S_2 and S_4 and includes blocks with conspicuously rotated S_2 fabrics. These later pseudotachylite units are related to a large fault running immediately southeast of these outcrops.

2.) MacLellan minesite, in the firebreak, 400 m north of the head frame (Fig. GS-20-6)

The bedrock here is heterolithic mafic breccia with a folded enclave of mafic metasedimentary rock (amphibole-garnet schist). One of the large, late faults runs immediately east of this outcrop, and the outcrop is cut by smaller splays of this structure. Both the large fault and its splays run parallel to the S_4 fabric in these rocks.

The metasediment enclave lies parallel to the S_2 foliation; within it, the foliation is a composite of S_{0-1-2}, picked out by amphibole growth. This composite foliation is intensively crenulated by S_4. The trace of this metasediment layer across these outcrops defines a mesoscale F_4 fold that plunges steeply to the north-northeast.

Pervasive silicification of the heterolithic mafic breccia is seen along both contacts with the metasediment layer; this alteration carries an amphibole and biotite growth, which carries the S_2 fabric in the breccia. Outcrop of the

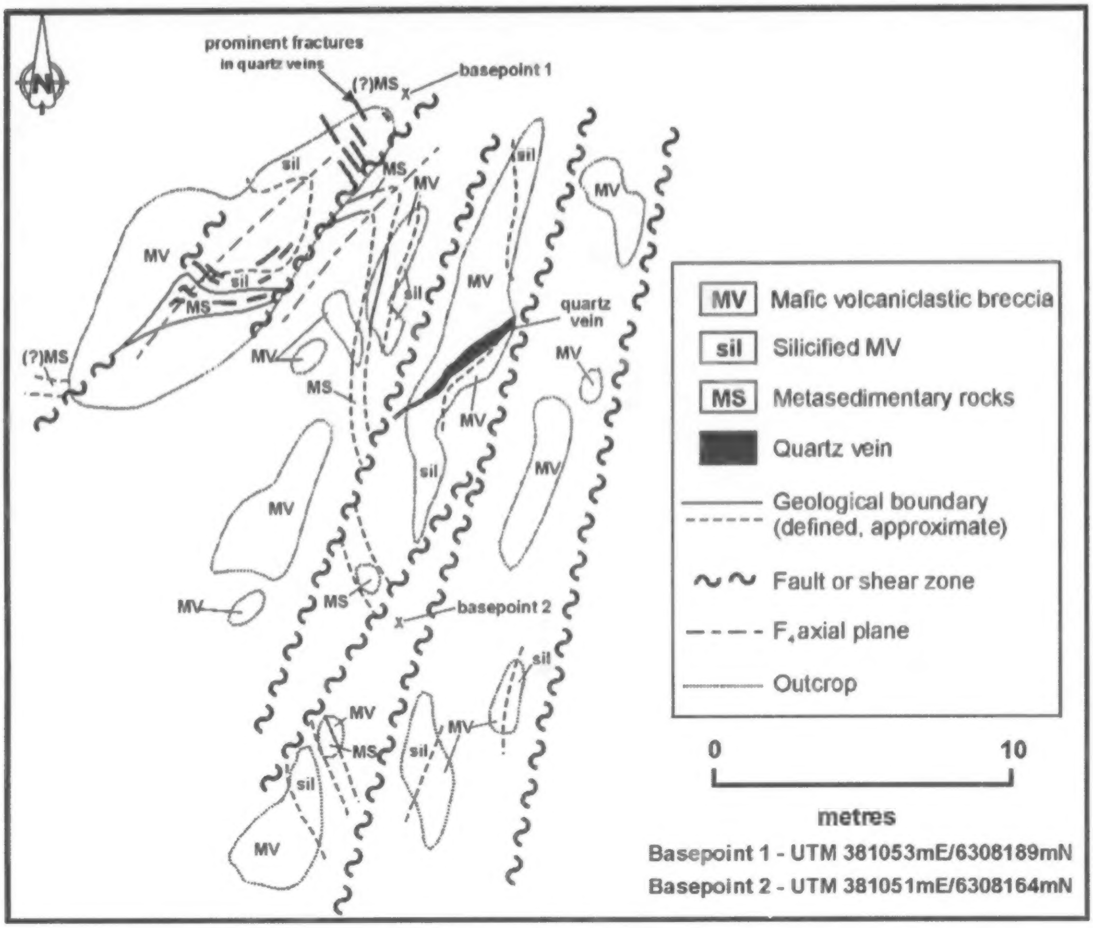

prominent fractures in quartz veins
(?)MS
basepoint 1
sil
MS
MV
MV
sil
MS
(?)MS
MV
MS
sil
MV
quartz vein
MV
MV
sil
MV
MV
MV
MS
basepoint 2
sil
MV
MS
sil
MV
sil
MV
MV Mafic volcaniclastic breccia
sil Silicified MV
MS Metasedimentary rocks
Quartz vein
Geological boundary (defined, approximate)
Fault or shear zone
F_4 axial plane
Outcrop
0
10
metres
Basepoint 1 - UTM 381053mE/6308189mN
Basepoint 2 - UTM 381051mE/6308164mN

Figure GS-20-6: Detailed outcrop map of the exposure in the fire break north of the MacLellan mine headframe.

metasediment layer picks out an F_4 fold and the metasedimentary rock is strongly crenulated by S_4. This layer is offset along faults parallel to S_4. Silicification overprinting S_2 is found in the wallrocks to these faults. At the northernmost point of these outcrops, a set of quartz veinlets in fractures is conjugate to these faults, and these veinlets are also associated with silicification.

Both S_2 and S_4 show signs of reactivation as fractures when either fabric lies parallel or nearly parallel to the late faults. Quartz veinlets with sulphide mineralization occur on both reactivated planes, and in the late fault conjugates.

3.) K-2 Zone (Fig. GS-20-7)

Mineralization here is contained within a ferruginous metasedimentary enclave that defines a southwest-closing F_2 fold with an isoclinal profile. The northern limb can be traced across these outcrops to the northeast. The southern limb persists and then vanishes, possibly around another closure (closing northeast), which is not exposed but is inferred by an F_2 vergence change. The F_2 minor folds at the south end of the trench show highly variable plunges, ranging from approximately 40°NE to 60°SW, that delineate a highly curvilinear hinge for the larger F_2 structure. Quartz stringer zones with silicification and sulphide mineralization run parallel to S_2 in the metapicrite of both footwall and hangingwall, with the metapicrite in the F_2 fold showing extensive silicification up to the metasediment contact.

Some of the larger quartz veins here show wallrock alteration that is sensitive to lithology. The most prominent examples of this are in areas that cross the metasediment-metapicrite contact and die out rapidly in the latter rock type as fractures surrounded by extensive growth of coarse amphibole.

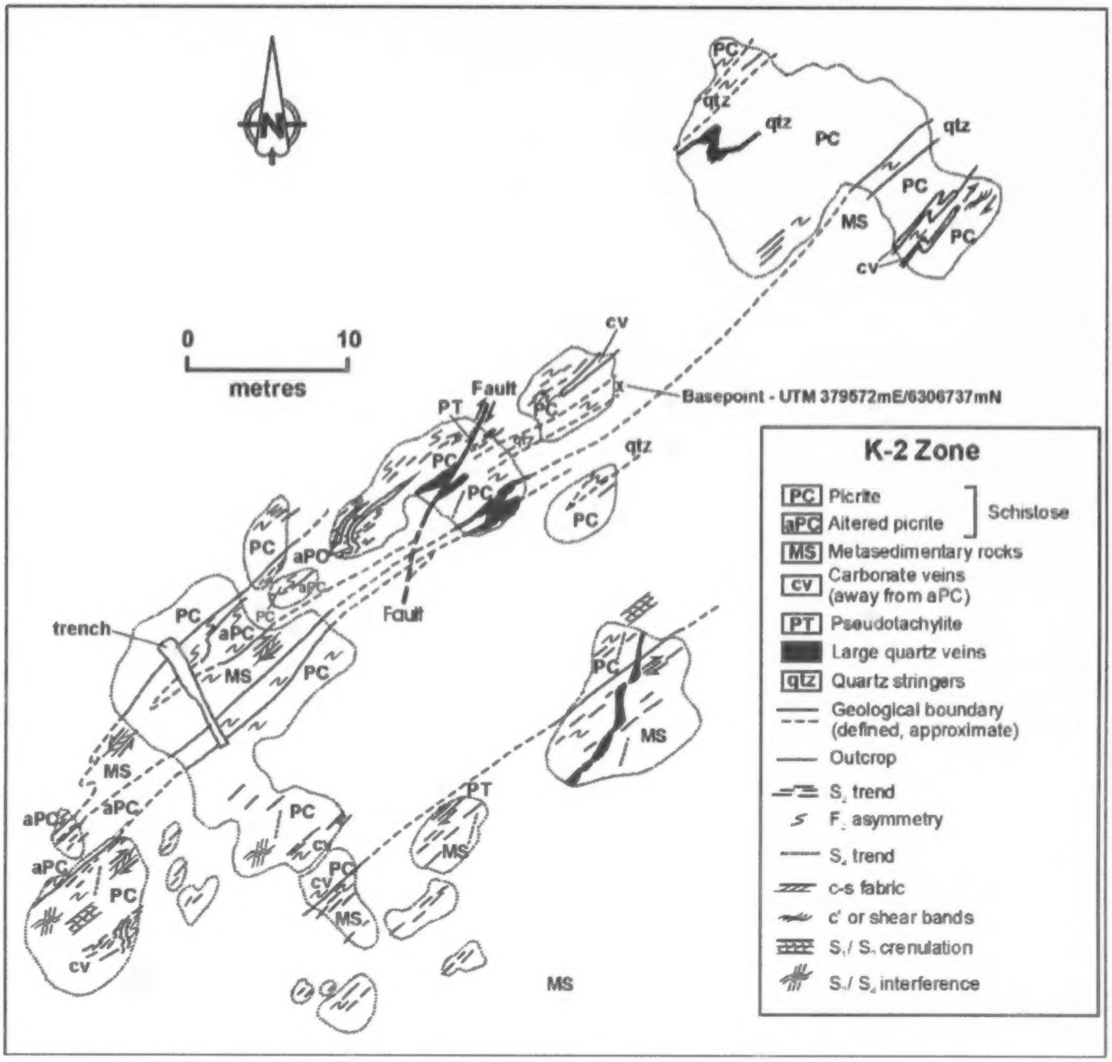

N
0
10
metres
PC
qtz
PC
qtz
PC
MS
PC
cv
cv
Fault
PT
PC
qtz
Basepoint - UTM 379572mE/6306737mN
qtz
PC
PC
PC
aPC
aPC
Fault
trench
PC
aPC
MS
PC
PC
MS
MS
aPC
aPC
aPC
PC
PC
cv
cv
PT
MS
PC
cv
MS
MS
K-2 Zone
PC Picrite
aPC Altered picrite
Schistose
MS Metasedimentary rocks
cv Carbonate veins (away from aPC)
PT Pseudotachylite
Large quartz veins
qtz Quartz stringers
Geological boundary (defined, approximate)
Outcrop
S_2 trend
F_2 asymmetry
S_4 trend
c-s fabric
c' or shear bands
S_2/ S_3 crenulation
S_2/ S_4 interference

Figure GS-20-7: Detailed outcrop map of the K-2 zone.

4.) "Rushed' zone and its roadside continuation (Fig. GS-20-8)

The 'Rushed zone' and its continuation can be traced in outcrop for nearly 1 km. At the southwest end (the 'Rushed' zone itself), it is contained in a metasedimentary enclave between heterolithic mafic breccia and a metapicrite body. The F_2 minor folds here show S-vergence with a shallow plunge to the northeast. A large F_2 fold closes around the metapicrite body into a mafic tectonite in which schist derived from heterolithic mafic breccia is intimately interlayered with metasediment, and in which all folds show Z-vergence and shear sense is consistently right lateral.

The mineralized zone along the metasediment contact can be traced along strike back to roadside outcrops, at which point the metapicrite pinches out and the metasediment enclave is completely enclosed in heterolithic mafic breccia with mafic metasedimentary layers (the more turbiditic facies of the breccia). Younging indicators in the breccia show top towards the metasedimentary enclave from both sides. However, from the point where the zone meets the road and to the northeast, F_2 fold vergence on the west side of the enclave has changed to Z-vergence. Fold axes throughout the area consistently plunge 15° and 30° to the northeast.

Eventually, the metasedimentary enclave becomes discontinuous as boudins in a distinct shear zone axial to the northeastward F_2 fold closure. Approximately 200 m northeast of the last outcrop of metasediment, Z-verging F_2 minor folds affect metasedimentary rocks in the breccia where facing on S_2 has reversed. This northeast closure of

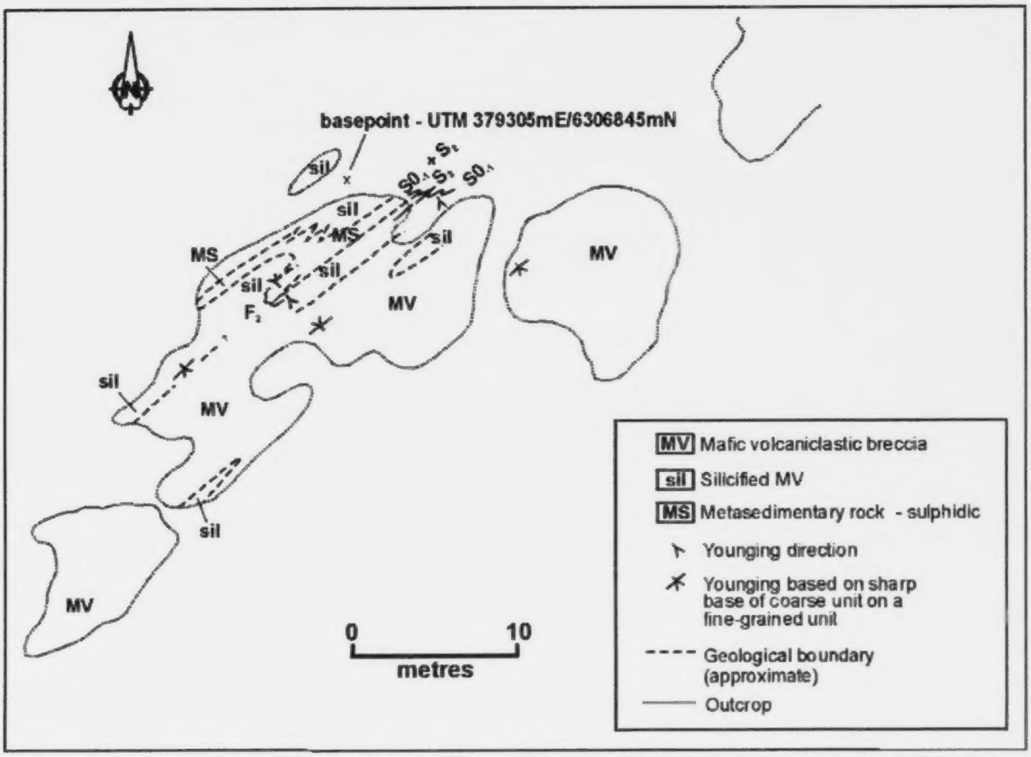

N
basepoint - UTM 379305mE/6306845mN
sil
MS
MV
F2
S0
S1
0
10
metres
MV Mafic volcaniclastic breccia
sil Silicified MV
MS Metasedimentary rock - sulphidic
Younging direction
Younging based on sharp base of coarse unit on a fine-grained unit
Geological boundary (approximate)
Outcrop

Figure GS-20-8: Detailed outcrop map of part of the 'Rushed' zone and its extension along the MacLellan mine road.

mineralized metasedimentary enclave appears to be an F_1 closure transposed into S_2. There is one locality where an oblique S_0-S_1 relationship is preserved. The larger structure here is an F_2 sheath, characterized by the change in vergence along strike in the same fold limb and the double closing of F_2 folds with the same plunge. The mineralized metasediment enclave forming the 'Rushed zone' extension itself defines an F_1 fold wrapped around the sheath.

CONCLUSIONS

1.) The heterolithic mafic breccia, which dominates this part of the Agassiz Metallotect, is a mafic volcaniclastic debris-flow deposit showing facies variation into more organized sandy-silty turbidite and eventually into mafic turbidite that is gradational into the mafic metasedimentary rocks of unit 4. Within the heterolithic mafic breccia, the more turbiditic rock types preserve way-up criteria based on the sharp and often erosive contacts between sandy and silty units. Detailed mapping of these criteria locally permits recognition of meso- to large-scale F_1 structures through the pervasive D_2 transposition.

2.) Progressive noncoaxial deformation and transposition during D_2, coupled with alteration and the development of pre-D_2 quartz and carbonate veins, has created a series of tectonite units that form mappable entities in their own right. These are hybrid rocks from which all or most primary characteristics have been obliterated. Examples include 1) the mafic tectonite derived from heterolithic mafic breccia, with or without metapicrite enclaves; and 2) mixed tectonite in which heterolithic mafic breccia, metapicrite, metabasalt, mafic metasedimentary rocks and alumino-siliceous metasedimentary rocks can all be identified as schlieren, ranging in scale from less than a metre to larger coherent boudins.

3.) The outcrop pattern of the Agassiz Metallotect between Lynn Lake and the MacLellan mine is dominated by D_2 structures, of which F_2 sheath folds are the most important. The left-lateral shear sense and S-folds associated with the short limbs, and the southwest-plunging F_2 minor folds are poorly represented, giving a strong bias toward right-lateral shear sense with Z-folds, and northeast-plunging F_2 minor folds in this area. This defines a major portion of a right-lateral strike-slip zone splaying northeast from the Johnson Shear Zone and encompassing a substantial portion of the exposed 'north belt' of the Lynn Lake greenstone belt.

ACKNOWLEDGMENTS

The authors thank Jennifer Kavalench and Jennifer Greville for their assistance. Paul Pawliw and Michael Gareau of Black Hawk Mining Inc. are thanked for their continued support of MGS research in the Lynn Lake belt. Geological Survey of Canada support to David Lentz was instrumental in conducting the research presented here. The review by Alan Bailes greatly improved the manuscript.

REFERENCES

Anderson, S.D. and Beaumont-Smith, C.J. 2001: Structural analysis of the Pool Lake–Boiley Lake area, Lynn Lake greenstone belt (NTS 64C/11); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 76–85.

Bateman, J.D. 1945: McVeigh Lake area, Manitoba; Geological Survey of Canada, Paper 45-14.

Beaumont-Smith, C.J. 2000: Structural analysis of the Johnson Shear Zone in the Gemmell Lake–Dunphy Lakes area, Lynn Lake greenstone belt (parts of NTS 64C/11, /12); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 57–63.

Beaumont-Smith, C.J., Anderson, S.D. and Bohm, C.O. 2001: Structural analysis and investigations of shear-hosted gold mineralization in the southern Lynn Lake greenstone belt (parts of NTS 64C/11, /12, /15, /16); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 67–75.

Beaumont-Smith, C.J. and Edwards, C.D. 2000: Detailed structural analysis of the Johnson Shear Zone in the west Gemmell Lake area (NTS 64C/11); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 64–68.

Beaumont-Smith, C.J., Lentz, D.R. and Tweed, E.A. 2000: Structural analysis and gold metallogeny of the Farley Lake gold deposit, Lynn Lake greenstone belt (NTS 64C/16); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 73–81.

Beaumont-Smith, C.J. and Rogge, D.M. 1999: Preliminary structural analysis and gold metallogeny of the Johnson Shear Zone, Lynn Lake greenstone belt (parts of NTS 64C/10, /11, /15); *in* Report of Activities 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 61–66.

Fedikow, M.A.F. 1983: Geological and geochemical investigations at the Agassiz Au-Ag deposit, Lynn Lake, Manitoba; *in* Report of Field Activities 1983, Manitoba Energy and Mines, Mineral Resource Division, p. 94–97.

Fedikow, M.A.F. 1986: Geology of the Agassiz stratabound Au-Ag deposit, Lynn Lake, Manitoba; Manitoba Energy and Mines, Geological Services, Open File Report OF85-5, 80 p.

Fedikow, M.A.F. 1992: Rock geochemical alteration studies at the MacLellan Au-Ag deposit, Lynn Lake, Manitoba; Manitoba Energy and Mines, Geological Services, Economic Geology Report ER92-1, 237 p.

Fedikow, M.A.F. and Gale, G.H. 1982: Mineral deposit studies in the Lynn Lake area; *in* Report of Field Activities 1982, Manitoba Energy and Mines, Geological Services, p. 44–54.

Fedikow, M.A.F., Baldwin, D.A. and Taylor, C. 1986: Gold mineralization associated with the Agassiz Metallotect and the Johnson Shear Zone, Lynn Lake greenstone belt, Manitoba; *in* 'Gold in the Western Shield', Canadian Institute of Mining and Metallurgy, Special Volume 38, p. 361–378.

Fedikow, M.A.F., Parberry, D. and Ferreira, K.J. 1991: Geochemical target selection along the Agassiz metallotect utilizing stepwise discriminate analysis; Economic Geology, v. 86, p. 588–599.

Gagnon, J.E. 1991: Geology, geochemistry and genesis of the Proterozoic MacLellan Au-Ag deposit, Lynn Lake greenstone belt, Manitoba; M.Sc. thesis, University of Windsor, Windsor, Ontario.

Gilbert, H.P., Syme, E.C. and Zwanzig, H.V. 1980: Geology of the metavolcanic and volcaniclastic metasedimentary rocks in the Lynn Lake area; Manitoba Department of Energy and Mines, Mineral Resources Division, Geological Paper GP80-1.

Hoffman, P.F. 1990: Subdivision of the Churchill Province and extent of the Trans-Hudson Orogen; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Staufer (ed.), Geological Association of Canada, Special Paper 37, p. 15–40.

Jones, L.R., Beaumont-Smith, C.J. and LaFrance, B. 2000: Preliminary structural and gold metallogenic studies at the Burnt Timber mine and surrounding area, Lynn Lake greenstone belt (NTS 64C/10); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 69–72.

Ma, G. and Beaumont-Smith, C.J. 2001: Stratigraphic and structural mapping of the Agassiz Metallotect near Lynn Lake, Lynn Lake greenstone belt (parts of NTS 64C/14, /15); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 86–93.

Ma, G., Beaumont-Smith, C.J. and Lentz, D.R. 2000: Preliminary structural analysis of the Agassiz Metallotect near the MacLellan and Dot Lake gold deposits, Lynn Lake greenstone belt (parts of NTS 64C/14, /15); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Surve,y p. 51–56.

McBirney, A.R. 1963: Factors governing the nature of submarine volcanism; Bulletin Volcanologique, v. 26, p. 455–469.

Mitchell, A.H.G. 1970: Facies of an early Miocene volcanic arc, Malekula Island, New Hebrides; Sedimentology, v. 14, p. 201–243.

Moore, J.G., Bryan, W.B., Beeson, M.H., and Normark, W.R. 1995: Giant blocks in the South Kona landslide, Hawaii; Geology, v. 23, p. 125–128.

Moore, J.G., Phillips, R.L., Grigg, R.W., Patterson, D.W. and Swanson, D.A. 1973: Flow of lava into the sea, 1969–71, Kilauea Volcano, Hawaii; Geological Society of America Bulletin, v. 84, p. 537–546.

GS-21 DISCOVERY OF A CARBONATITE COMPLEX AT EDEN LAKE (NTS 64C9), MANITOBA

by A.H. Mumin[1]

Mumin, A.H. 2002: Discovery of a carbonatite complex at Eden Lake (NTS 64C9), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 187-197.

SUMMARY

Reconnaissance and detailed geological mapping and sampling carried out in the Kwaskwaypichikun region (KPK), near Eden Lake, has led to the recognition and discovery of a large carbonatite complex enriched in rare earth elements (REEs). The area was selected as a priority target with potential to host a hydrothermal iron-oxide copper-gold (IOCG- or Olympic Dam–type) deposit. The KPK region is underlain by alkaline igneous rocks ranging from K-feldspar–rich pegmatite and syenite to metasomatized intermediate, mafic and ultramafic bodies. The most striking feature of the complex is an extensive area of hydrothermal and magmatic stockwork veining and breccia exposed in outcrop over an area of at least 7 km^2. Early rocks of the complex include a series of intermediate (monzonitic) mafic and ultramafic rocks and paragneiss. These rocks are pervasively shattered and veined to produce blocky breccias. Syenitic veins, dikes and plugs invade the shatter zone in a complex stockwork. In the final phase of magmatic activity, K-feldspar- and quartz-rich pegmatite dikes form a late superimposed stockwork disrupting the earlier rocks.

Carbonatite dikes and plugs were unexpectedly discovered at three locations, and evidence suggests there may be many more. The carbonatite bodies are closely associated with syenite and fenitic alteration, and are presently thought to predate the pegmatite dikes. Alkali metasomatism affects the entire complex: Na alteration occurs as pervasive to patchy replacement of early phases and as ubiquitous hydrothermal veins and veinlets; and later stages of hydrothermal alteration include K±Na and K-carbonate metasomatism in veins and patches. The youngest phase of hydrothermal alteration includes large areas of pervasive hematization, and a few narrow, late quartz veins and veinlets.

The elements F, Ba, Sr, U, Th, Sc, Y, La, Ce, Sm, Nd, Pr, Eu, Gd, Dy, Tb, Tm, Er, Yb and Lu are variably enriched throughout the complex. Significant REE enrichments occur in all hydrothermally metasomatized rocks, including syenite and intermediate (monzonitic), mafic and ultramafic rocks. Hydrothermal veins, including aegirine-augite±K-feldspar or amphibole (usually mixed), K-feldspar and K-feldspar–carbonate, are strongly enriched in REE. The highest REE concentrations encountered to date are in the carbonatite dikes (up to 16 129 ppm total REE, 9764 ppm Sr and 745 ppm Y) and in hydrothermal REE-rich veins (up to 138 000 ppm total REE, 5307 ppm Y and 5465 ppm Th+U). Local enrichments in Cu and Ag were also encountered.

This paper reports only on the preliminary observations and results of work that was carried out mainly during a five-week period in July and August 2002. More detailed work on the geology, structure, mineralogy, geochemistry and mineralization of the complex is in progress.

INTRODUCTION

The eastern shore of Eden Lake in the Kwaskwaypichikun region was identified as a first-priority target with potential to host a hydrothermal iron-oxide copper-gold (IOCG- or Olympic Dam–type) deposit (Mumin, GS-11, this volume). The region of interest was previously mapped as aegirine-augite syenite and monzonite (Cameron, 1988; McRitchie, 1989; Fedikow et al., 1993), and was known to host several small radiometric U-Th and REE showings containing britholite and/or allanite (McRitchie, 1989; Young and McRitchie, 1990; Gunter et al., 1995; Fedikow et al., 1994; Arden and Halden, 1999). Geochemical investigations on aegirine-bearing monzonite by Halden and Fryer (1999) indicated anorogenic magmatism of probable depleted, altered, mantle-derived material. However, detailed mapping of the region had not been carried out until the present project. A five-week program of reconnaissance and detailed mapping and sampling was funded primarily by Rare Earth Metals Corp. of Vancouver. Reconnaissance work was carried out over an area of approximately 30 km^2, extending from Kwaskwaypichikun Bay south to within approximately 2 km of the Numakoos River (Fig. GS-21-1). Detailed mapping at 1:2000 scale was completed over two separate gridded blocks covering approximately 4 km^2 (Fig. GS-21-2), and four additional smaller blocks were remapped in greater detail (1:500 scale; Fig. GS-21-3).

Approximately 140 samples were collected and analyzed for 43 elements by inductively coupled plasma–mass spectrometry (ICP-MS), utilizing a lithium borate fusion technique for enhanced accuracy in REE detection. Check assays and geochemical orientation work are in progress.

---

[1] Department of Geology, Brandon University, Brandon, Manitoba R7A 6A9

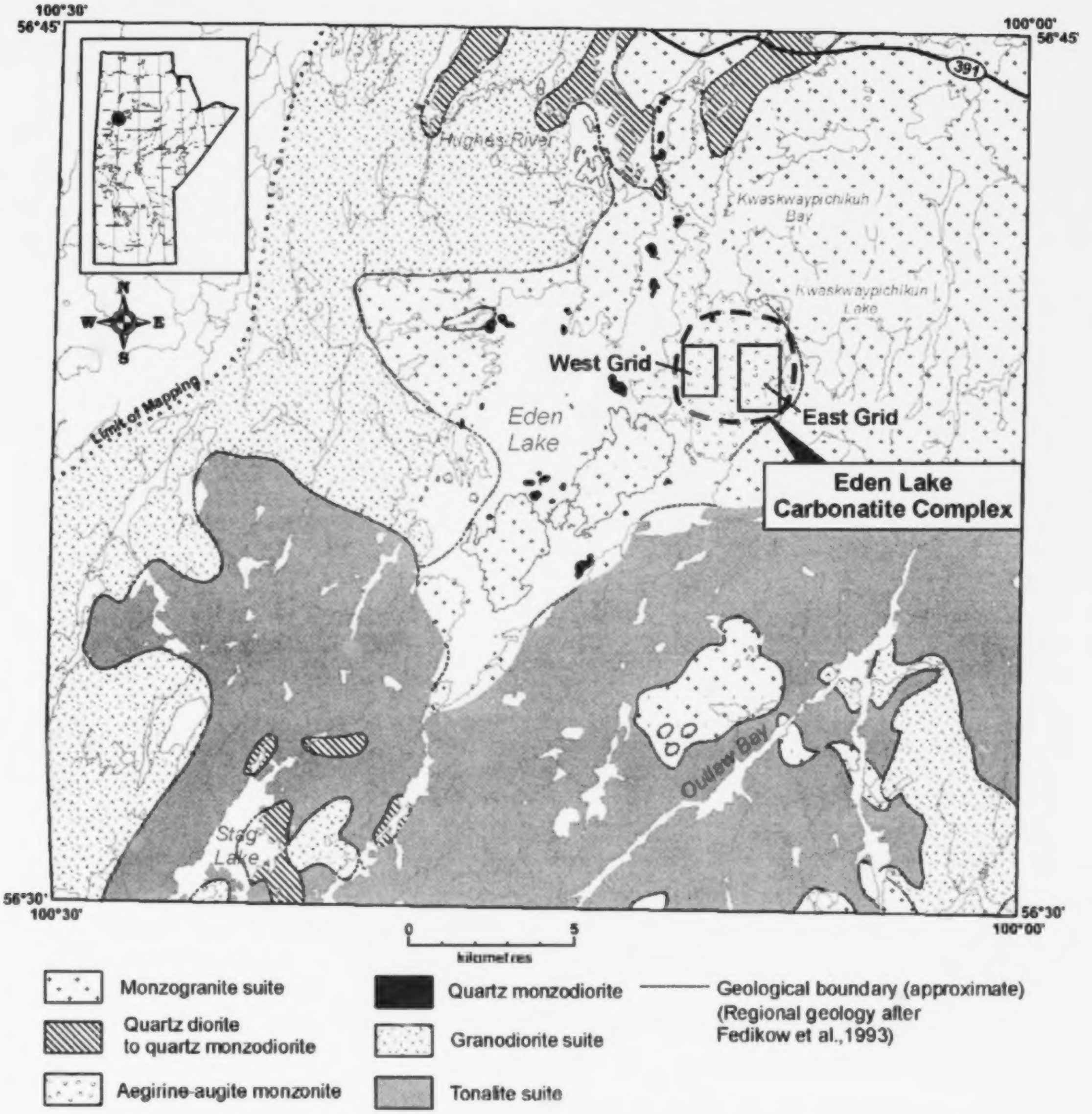

100°30'
56°45'
100°00'
56°45'
391
Hughes River
Kwaskwaypichikuh Bay
Kwaskwaypichikun Lake
N
W
E
S
Limit of Mapping
West Grid
East Grid
Eden Lake
Eden Lake Carbonatite Complex
Stag Lake
Outlaw Bay
56°30'
100°30'
56°30'
100°00'
0
5
kilometres
Monzogranite suite
Quartz diorite to quartz monzodiorite
Aegirine-augite monzonite
Quartz monzodiorite
Granodiorite suite
Tonalite suite
Geological boundary (approximate)
(Regional geology after Fedikow et al.,1993)

Figure GS-21-1: Regional geology of the Eden Lake area (after Fedikow et al., 1993), showing location of reconnaissance and detailed work.

PRELIMINARY OBSERVATIONS ON THE GEOLOGY OF THE EDEN LAKE CARBONATITE COMPLEX

The Kwaskwaypichikun region is underlain by an extensive hydrothermal and magmatic stockwork and breccia. Intermediate (monzonitic), mafic and ultramafic rocks occur as coarse blocky breccia and disaggregated stocks and dikes with varying degrees of metasomatic alteration (Fig. GS-21-4). Paragneiss of unknown affinity is associated with some of the monzonite and mafic rocks. These rocks are ubiquitously cut and disaggregated by a stockwork of aphanitic to medium-grained syenite to quartz syenite stocks, dikes and small veins (Fig. GS-21-4). The syenite bodies range from less than 1 cm to more than 100 m in thickness, with coalescing veins and dikes forming larger syenite bodies. The youngest magmatic rock in the complex is pyroxene-bearing quartz+K-feldspar pegmatite. It forms medium- to very coarse grained dikes and stockwork veins, with individual dikes up to 5 m thick and extending for several hundred metres along strike.

Remnants of early sedimentary hostrocks have not been identified, with the possible exception of the paragneiss.

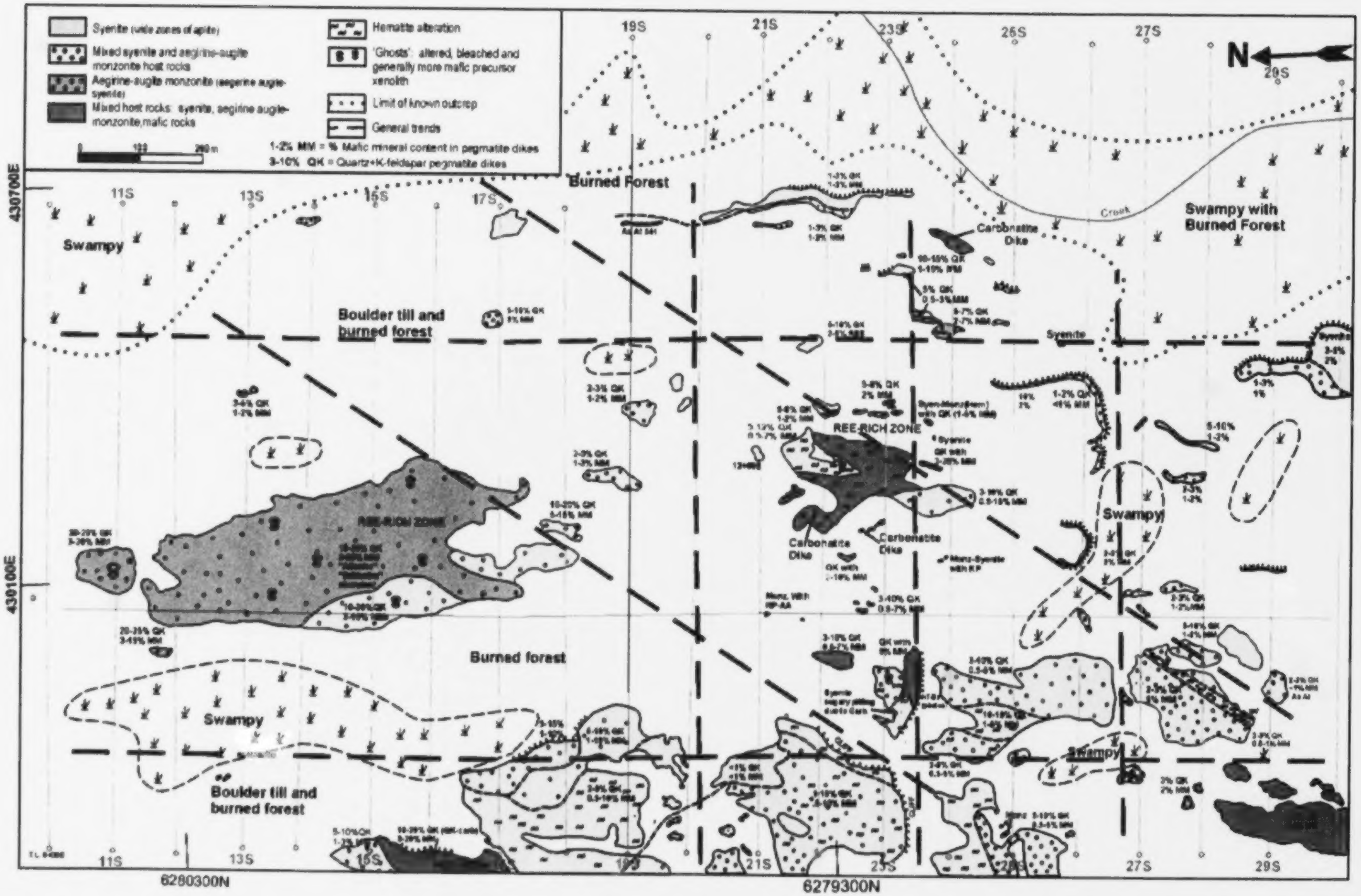

Syenite (wide zones of aplite)
Mixed syenite and aegirine-augite monzonite host rocks
Aegirine-augite monzonite (aegerine augite-syenite)
Mixed host rocks: syenite, aegirine augite-monzonite,mafic rocks
Hematite alteration
'Ghosts': altered, bleached and generally more mafic precursor xenolith
Limit of known outcrop
General trends
0
100
200 m
1-2% MM = % Mafic mineral content in pegmatite dikes
3-10% QK = Quartz+K-feldspar pegmatite dikes
N
430700E
430100E
6280300N
6279300N
11S
13S
15S
17S
19S
21S
23S
25S
27S
29S
Swampy
Boulder till and burned forest
Burned Forest
Swampy with Burned Forest
Creek
Carbonatite Dike
Syenite
REE-RICH ZONE
Carbonatite Dike
Carbonatite Dike
Swampy
Burned forest
Swampy
Boulder till and burned forest
Swampy

Figure GS-21-2: Geology of the East grid.

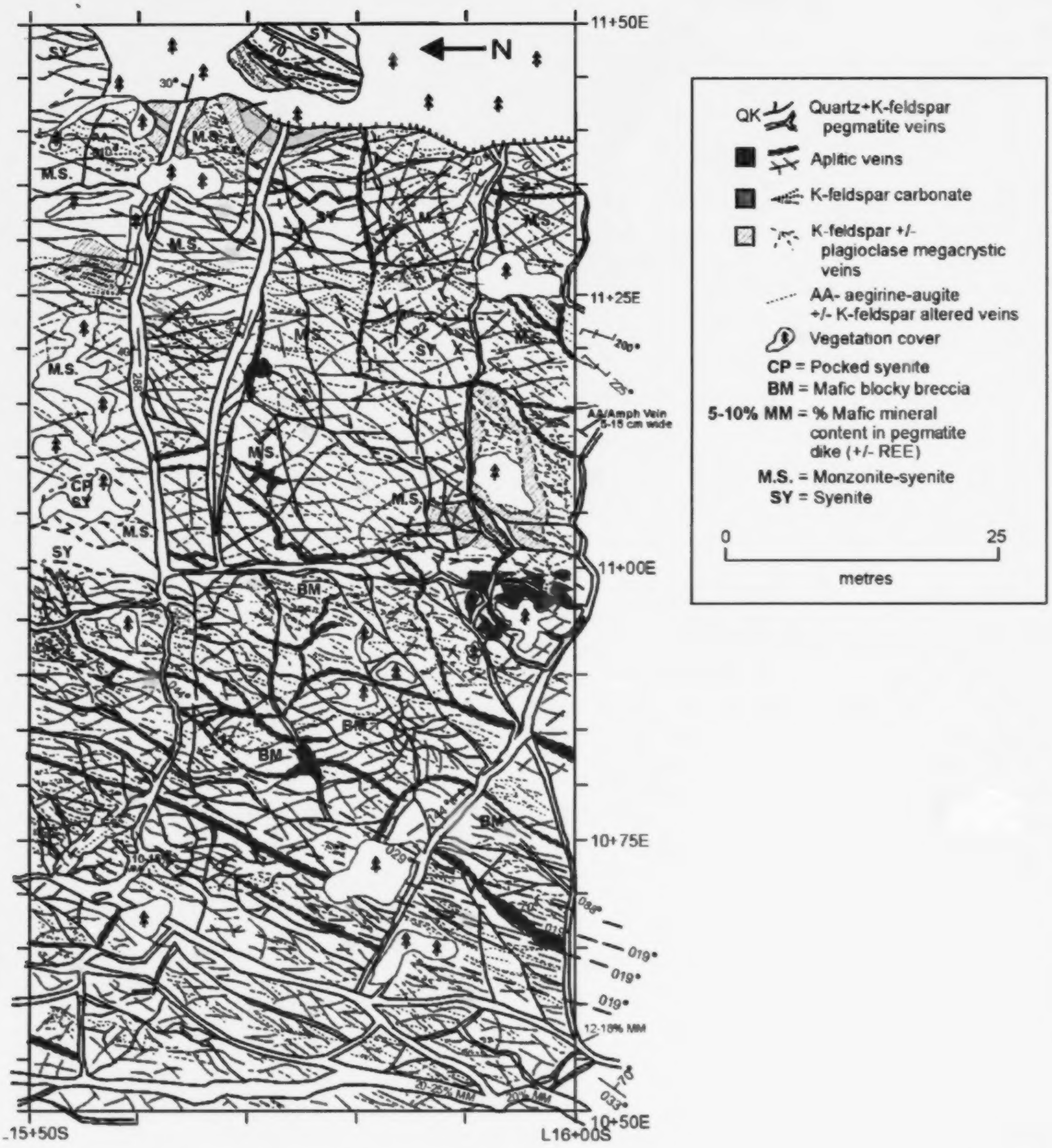

11+50E
11+25E
11+00E
10+75E
10+50E
15+50S
L16+00S
N
QK
Quartz+K-feldspar pegmatite veins
Aplitic veins
K-feldspar carbonate
K-feldspar +/- plagioclase megacrystic veins
AA- aegirine-augite +/- K-feldspar altered veins
Vegetation cover
CP = Pocked syenite
BM = Mafic blocky breccia
5-10% MM = % Mafic mineral content in pegmatite dike (+/- REE)
M.S. = Monzonite-syenite
SY = Syenite
0
25
metres
AA/Amph Vein 5-15 cm wide
12-18% MM
20-25% MM
20% MM
SY
M.S.
BM
CP

Figure GS-21-3a: Structural detail for part of the East grid, showing the intensity and complexity of veining in the shatter zone.

Some rocks may be volcanic in origin, with their primary textures obliterated, but this possibility remains uncertain. Large parts of the region were mapped as zones of 'mixed rocks', due to extensive intermixing and disaggregation of the different host units of the complex (Fig. GS-21-4).

Structure

Three distinct structural trends intersect in the Kwaskwaypichikun region. North-, east- and northeast-trending structures control the orientations of many veins and dikes (Fig. GS-21-2). Additionally, vein- and dike-filled fractures of the shatter zone occur in all orientations, with dips ranging from near-horizontal to vertical (generally

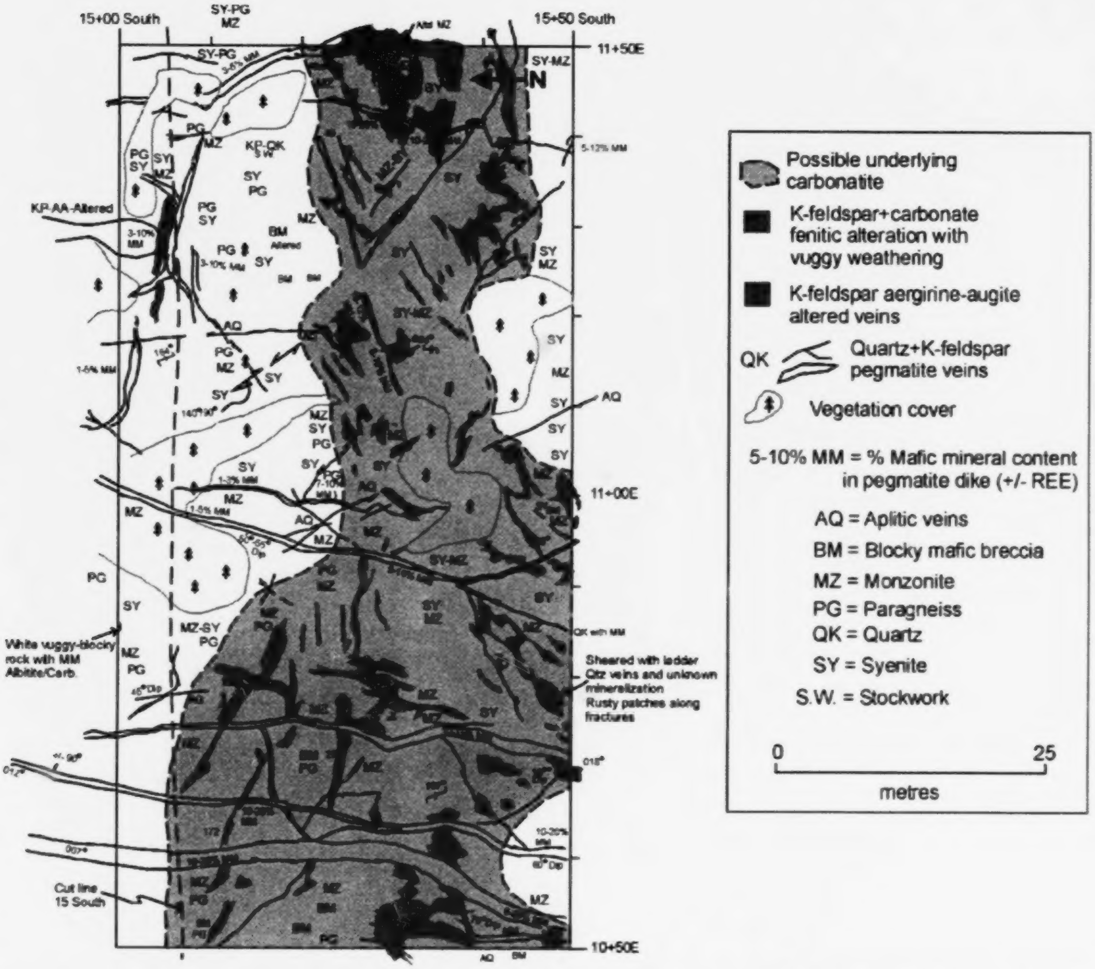

15+00 South
15+50 South
SY-PG MZ
11+50E
11+00E
10+50E
N
KP-AA-Altered
White vuggy-blocky rock with MM Albitite/Carb.
Sheared with ladder Qtz veins and unknown mineralization
Rusty patches along fractures
Cut line 15 South
Possible underlying carbonatite
K-feldspar+carbonate fenitic alteration with vuggy weathering
K-feldspar aegirine-augite altered veins
QK Quartz+K-feldspar pegmatite veins
Vegetation cover
5-10% MM = % Mafic mineral content in pegmatite dike (+/- REE)
AQ = Aplitic veins
BM = Blocky mafic breccia
MZ = Monzonite
PG = Paragneiss
QK = Quartz
SY = Syenite
S.W. = Stockwork
0
25
metres

Figure GS-21-3b: Detailed geology, showing the relationship of K-feldspar–carbonate fenite bodies to quartz–K-feldspar pegmatite dikes and the 'shattered' host rocks, East grid. Location of possible underlying carbonatite is indicated.

ranging from approx. 30° to vertical). Evidence for domal jointing was observed at several localities as shallow-dipping, layer-cake, weathered syenite (Fig. GS-21-5). Domal jointing is known to occur in the domed rocks overlying large intrusions. The result of intersecting structural features combined with pervasive hydrothermal and magmatic injections is an extensive stockwork and angular blocky breccia covering at least 7 km^2 of the Kwaskwaypichikun region.

Polymictic, diatreme-like structural and hydrothermal breccias with partially milled, rounded to angular clasts are locally exposed in irregular patches (Fig. GS-21-6). One of these breccias with variably altered and milled clasts is exposed along an east-trending fault scarp (Fig. GS-21-7). Polymictic clasts are cemented in a K-feldspar– and carbonate-rich matrix. The nature of these breccias remains under investigation. Late fractures are common in some areas of the complex, most of them trending in a northeasterly direction. They are often associated with hematitic alteration, and some of these late fractures are filled with narrow (centimetre-scale), opaque to translucent quartz veins carrying trace amounts of sulphide and other minerals.

Hydrothermal alteration

Widespread hydrothermal alteration has affected host rocks throughout the carbonatite complex. Aegirine-augite is variably disseminated in syenite and intermediate (monzonite), mafic and ultramafic rocks (Fig. GS-21-4). Aegirine-augite also occurs as narrow, hydrothermal veins and veinlets, often intergrown with K-feldspar or with K-feldspar selvages, and occasionally with amphibole. These aegirine-augite–bearing veins typically constitute 0.5 to

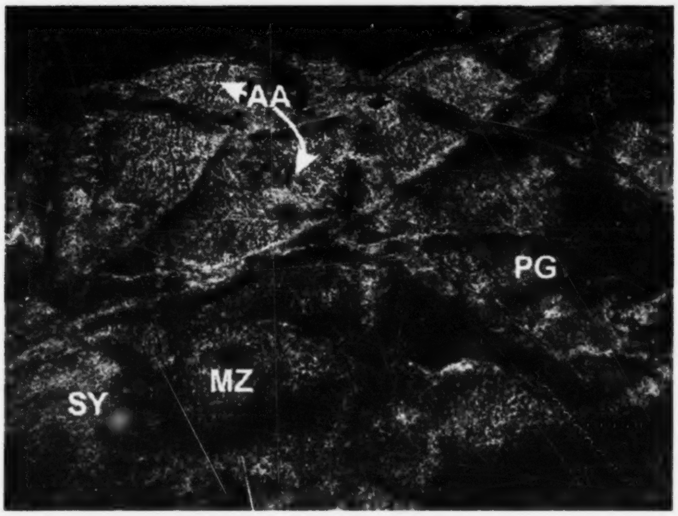


Figure GS-21-4: Monzonite and paragneiss host rocks are shattered and veined with fine-grained syenite to produce the coarse, blocky breccia, East grid. Abbreviations: AA, aegirine-augite–K-feldspar veins; MZ, monzonite; PG, paragneiss; SY, syenite.

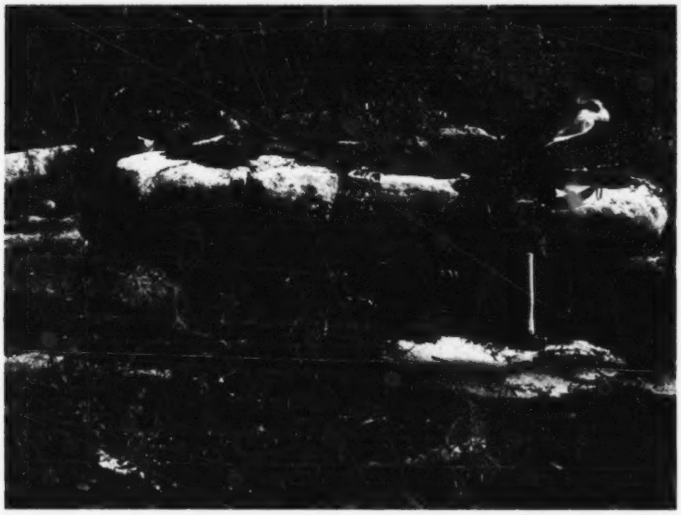


Figure GS-21-5: Layer-cake weathered syenite, West grid.

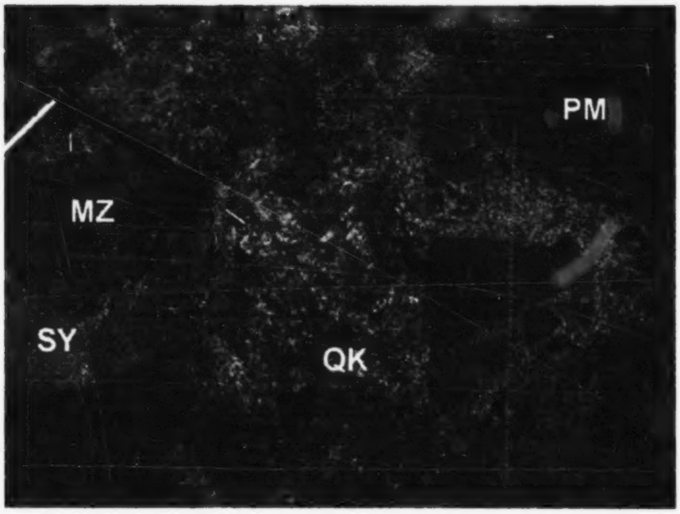


Figure GS-21-6: Blocky, angular, polymictic breccia cut by a small quartz+K-feldspar pegmatite dike, West grid. Abbreviations: MZ, monzonite; PM, porphyroblastic mafic rock; QK, quartz–K-feldspar pegmatite; SY, syenite.

Figure GS-21-7: Diatreme-like breccia with partially altered, subrounded to angular polymictic clasts, associated with an east-trending structure, East grid.

3% of the rock mass (Fig. GS-21-8). Whitish grey bleached zones, which appear to be the result of plagioclase metasomatism, occur locally in small patches. Some mafic and ultramafic rocks are altered to mica schist.

Coarse-grained to pegmatitic K-feldspar±aegirine-augite veins and dikes occur as late hydrothermal-magmatic features. In many areas, megacrystic K-feldspar rich veins and patches occur with abundant carbonate in the form of disseminated grains, blebs and veinlets. The carbonate weathers easily, leaving these rocks with a sugary to vuggy surface texture (Fig. GS-21-9).

Hematization is common and pervasive in some parts of the complex. It is particularly evident in altered syenite, and locally affects late quartz–K-feldspar dikes. The hematite alteration is most common as pervasive turbid zones in and around feldspar, but also occurs as small veinlets and locally as specularite. Hematization is commonly associated with late, northeast-trending fractures. Minor, narrow, opaque to translucent quartz veins also occupy some of the northeast-trending fractures and contain trace amounts of sulphide minerals.

The evolution in hydrothermal alteration of the complex appears to progress from early Na+Fe metasomatism to alkali metasomatism (K±Na), K+carbonate metasomatism, hematization and finally minor quartz veining.

Mineralization

The entire complex as presently delineated is variably enriched in rare earth elements plus or minus Sc, Y, Ba, Sr, F, U, Th, Cu and Ag. The enrichments vary according to rock type and/or degree of hydrothermal alteration, and include

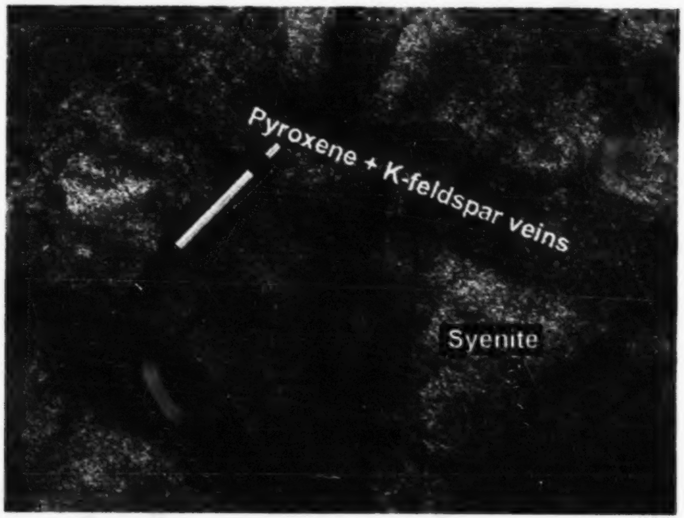


Figure GS-21-8: Pyroxene (aegirine-augite) and K-feldspar veins, East grid.

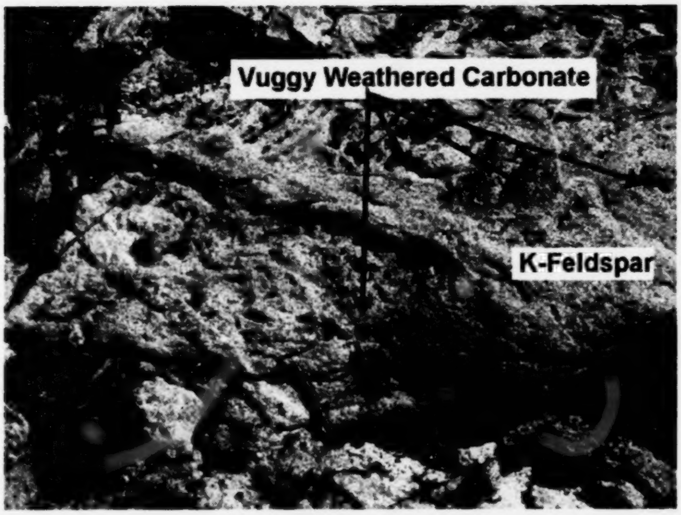


Figure GS-21-9: K-feldspar- and carbonate-rich veins with vuggy surface weathering, East grid.

several styles of potentially economic mineralization. All hydrothermally altered rocks, including syenite, intermediate (monzonite), mafic and ultramafic units, and quartz+K-feldspar pegmatite were found to be enriched in REEs. Altered syenite contains up to 4000 ppm REEs, intermediate and mafic hostrocks up to 1925 ppm REEs, and quartz+K-feldspar pegmatite (Fig. GS-21-10) up to 1150 ppm total REEs and up to 662 ppm total heavy rare earth elements (HREEs).

Ubiquitous hydrothermal veins with pyroxene (aegirine-augite), pyroxene+K-feldspar (Fig. GS-21-8) and pyroxene+amphibole+feldspar are also consistently enriched in REEs (up to 10 000 ppm). The most spectacular grades encountered to date are from REE-rich veins (mineralogy under investigation) that range up to 15 cm in width and have undelineated lengths that can exceed 50 m (Fig. GS-21-11). Total REE contents in these veins range from 34 000 to 138 000 ppm, including HREE contents ranging from 1416 to 6851 ppm. These veins are strongly enriched in Th and U, with values up to 3031 ppm Th and 2434 ppm U. The REE veins that were sampled follow the northeast-trending structures, but other orientations were also noted.

The carbonatite dikes and plugs discovered in the complex are also strongly enriched in REEs, Sr and Y. The carbonatite contains abundant calcite, with feldspar, pyroxene, apatite, other mafic minerals and as yet undetermined REE-bearing phases (Fig. GS-21-12). Values up to 16 130 ppm total REEs, 835 ppm HREE, 9764 ppm Sr and 745 ppm Y are present in samples of weathered carbonatite collected during the present program. The margins of the carbonatite are characterized by vuggy-weathered, megacrystic, fenite-altered rocks rich in feldspar+pyroxene+carbonate. These altered selvages are also strongly enriched in REEs, with values up to 7700 ppm total REEs, including 409 ppm HREEs (Fig. GS-21-13).

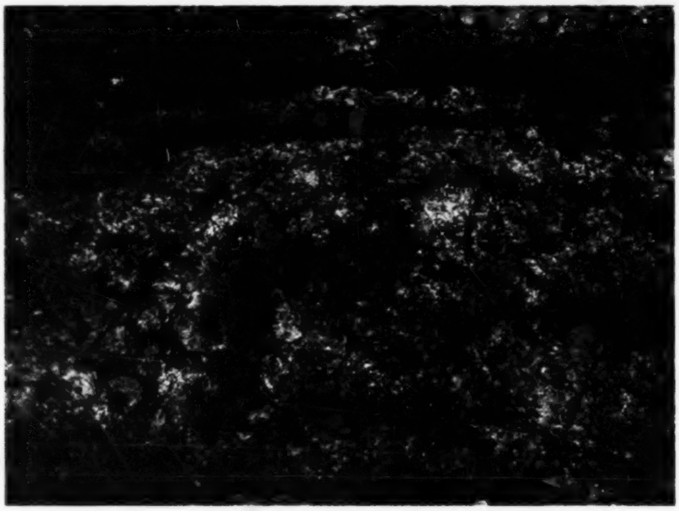


Figure GS-21-10: Quartz+K-feldspar pegmatite dike enriched in REEs, East grid.

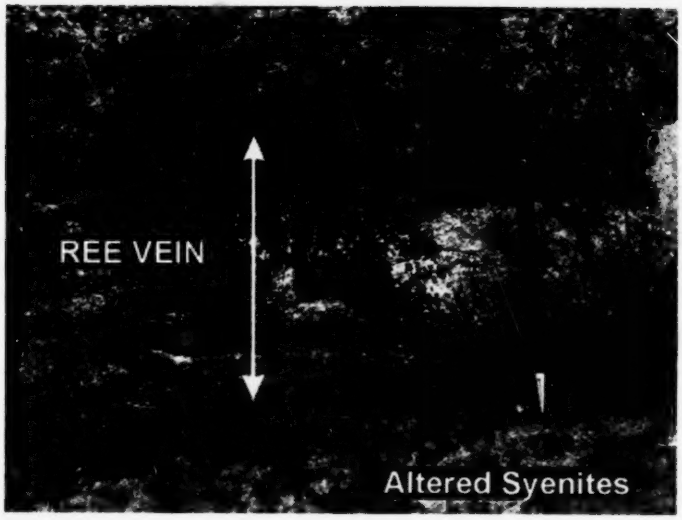

REE VEIN
Altered Syenites

Figure GS-21-11: Detail of one of the high-grade REE-rich veins, East grid.

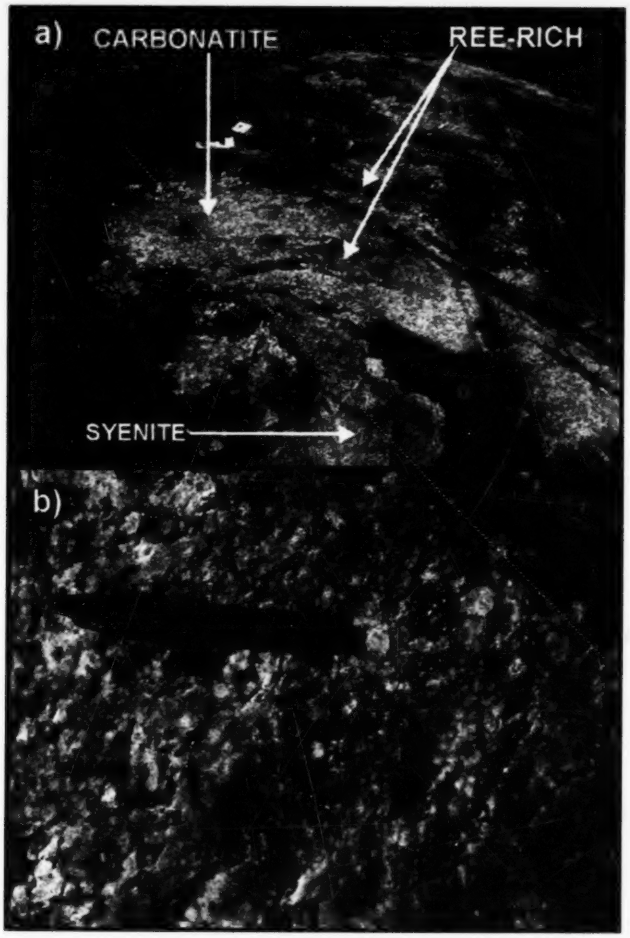

a)
CARBONATITE
REE-RICH
SYENITE
b)

Figure GS-21-12: a) Part of a small group of REE-mineralized carbonatite dikes and plugs located near line 22S, East grid. b) Detail of the carbonate-rich portion of the carbonatite dike located near line 23S, East grid.

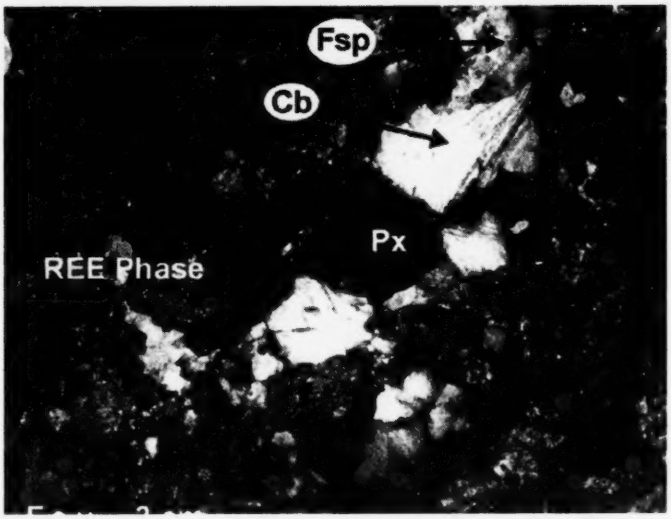


Figure GS-21-13: Fenite selvage of the carbonatite at line 22S, East grid. The selvage forms a vuggy-weathered aggregate of K-feldspar, remnant carbonate, pyroxene and REE-bearing minerals. Abbreviations: Px, pyroxene; Cb, carbonate; Fsp, K-feldspar.

DISCUSSION AND CONCLUSIONS

The hydrothermal and magmatic stockwork and breccia complex in the Eden Lake area has the characteristics of a large carbonatite complex, and is comparable in various aspects to carbonatite complexes worldwide. The extensive stockwork and breccia zone is indicative of 'shatter zones' capping major subvolcanic intrusions. The alkali-rich rocks, including syenite, aegirine-augite monzonite and mafic and ultramafic rocks, are a common intrusive suite hosting and genetically related to carbonatite. Alkali metasomatism (in the form of alkali-rich pyroxene, amphibole, feldspar and mica), carbonatization and hematization are typical hydrothermal-alteration types associated with carbonatite intrusions, and are lumped together under the term 'fenitic' alteration, after the Fen complex in Norway (Barth and Ramberg, 1966).

The nature and distribution of the intrusive rocks, stockworks, breccias and hydrothermal alteration strongly suggest the presence of one or more large, underlying carbonatite bodies. In particular, some types of fenitic alteration (e.g., the alteration zone illustrated in Figure GS-21-3b) are thought to proximally overlie hidden carbonatite bodies. The carbonatite bodies discovered in three areas during the present program are thought to be small fingers protruding through a shattered and fenitized carapace overlying one or more larger carbonatite bodies. The carbonatite bodies are very soft and unstable, compared to the syenite and other rocks of the complex, and consequently weather recessively. Any large carbonatite bodies presently subcropping at the bedrock surface will be hidden in low ground beneath glacial till, swamps or lakes.

The Eden Lake carbonatite complex is of particular interest due to its rare earth element enrichments over an extensive area. The complex contains several types of potentially economic mineralization, including 1) high-grade veins, 2) the carbonatite bodies, 3) fenitic selvages of the carbonatite bodies, and 4) altered syenite and other host rocks. In addition, the complex contains widespread enrichments in the more valuable HREEs, plus scandium. At the time of writing, ongoing work (trenching) had uncovered copper-sulphide+fluorite mineralization in altered syenite marginal to one of the exposed carbonatite dikes. The potential economic implications of the different types of mineralization are under investigation.

Discovery of the Eden Lake carbonatite bodies as a result of a search for hydrothermal iron-oxide copper-gold (Olympic Dam–type) deposits raises a number of very intriguing questions regarding a possible genetic relationship between IOCG (Olympic Dam–type) deposits and carbonatite complexes. The world's largest rare earth element deposits are Bayan Obo in China. They are routinely classified as IOCG-type deposits, although several investigators have suggested that they may be related to carbonatite complexes (Zhou et al., 1980; Mariano, 1989; Smith and Chengyu, 2000). Vielreicher et al. (2000) and Harmer (2000) have recently discussed the similarities of the Phalaborwa carbonatite to IOCG-type deposits. The relationship between carbonatite and kimberlite is well documented, and these two types of ultramafic-associated, mantle-derived magmas are often found within the same complex or district. The implications of these relationships have yet to be determined at Eden Lake.

RECOMMENDATIONS

A surprising variety of mineralization styles was encountered within the Eden Lake carbonatite complex, and several of these may have economic potential. The nature of the intrusive rocks of the complex requires detailed examination in order to properly identify and classify them, and to 'see' through the alteration overprints. Geochronology has already been initiated by the MGS to constrain the age of mineralization, to assist with the IOCG scoping study, and to help with further exploration in and around the complex.

A considerable amount of additional detailed mapping, sampling, petrography and geochemistry is critical to fully understanding this interesting geological phenomenon, and is imperative for the continued exploration and ultimate delineation of a mineral resource. Trenching was underway at the time of writing, and diamond drilling is required (following the detailed surface work) to test the complex below the surface cover, where any large carbonatite body is likely to be hidden.

ACKNOWLEDGMENTS

This project was funded primarily by Rare Earth Metals Corp. of Vancouver. Discussions with many members of the Manitoba Geological Survey were instrumental in selecting Eden Lake as a priority target for the initial IOCG (Olympic Dam) scoping study. John Camier was an invaluable partner in completing the fieldwork and logistics for this project. The work was funded, in part, by the Manitoba Geological Survey and by an NSERC research grant to the author.

REFERENCES

Arden, K.M. and Halden, N.M. 1999: Crystallization and alteration history of britholite in rare-earth element-enriched pegmatitic segregations associated with the Eden Lake complex, Manitoba, Canada; The Canadian Mineralogist, vol. 37. p. 1239–1253.

Barth, T.F.W. and Ramberg, I.B. 1966: The Fen circular complex; *in* Carbonatites, Interscience Publishers, John Wiley & Sons Ltd.

Cameron, H.D.M. 1988: Geology of the Eden Lake area; Manitoba Energy and Mines, Geological Services Branch, Geological Report GR84-2, 18 p.

Gunter, R., Fedikow, M.A.F., McRitchie, W.D. and Kowalyk, E. 1995: The Eden Lake rare earth element occurrence – metallurgy, geochemical and ground scintillometer surveys (NTS 64C/9), *in* Report of Activities 1995, Manitoba Energy and Mines, Geological Services, p. 11–16.

Halden, N.M. and Fryer, B.J. 1999: Geochemical characteristics of the Eden Lake complex: evidence for anorogenic magmatism in the Trans-Hudson Orogen, Can. J. Earth Sci. v. 36, p. 91–103.

Harmer, R.E. 2000: Mineralisation of the Phalaborwa Complex and the carbonatite connection in iron oxide-Cu-Au-U-REE deposits; *in* Hydrothermal Iron Oxide Copper-Gold and Related Deposits, A Global Perspective, Australian Mineral Foundation.

Mariano, A.N. 1989: Economic geology of rare earth elements; Reviews in Mineralogy, v. 21, p. 309–337.

McRitchie, W.D. 1989: Ground scintillometer reconnaissance of the Eden Lake aegirine-augite monzonites; *in* Report of Activities 1989, Manitoba Energy and Mines, Geological Services, p. 7–12.

Smith, M. and Chengyu, W. 2000: The geology and genesis of the Bayan Obo Fe-REE-Nb deposit: a review; *in* Hydrothermal Iron Oxide Copper-Gold and Related Deposits, A Global Perspective, Australian Mineral Foundation, p. 271–281.

Vielreicher, N.M., Groves, D.I. and Vielreicher, R.M. 2000: The Phalaborwa (Palabora) deposit and its potential connection to iron-oxide copper-gold deposits of Olympic Dam type; *in* Hydrothermal Iron Oxide Copper-Gold and Related Deposits, A Global Perspective, Australian Mineral Foundation, p. 321–329.

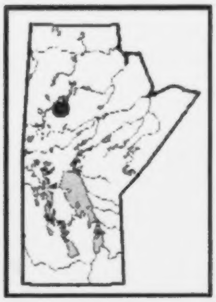
Young, J. and McRitchie, W.D. 1990: REE investigations, Eden Lake intrusive suite (NTS 64C/9); *in* Report of Activities 1990, Manitoba Energy and Mines, Geological Services, p. 9–19.

Zhou, Z., Gongyuan, L., Tongyun, S. and Yunguan, L. 1980. On the geological characteristics and the genesis of the dolomitic carbonates at Bayan Obo, Inner Mongolia; Geological Reviews, v. 26, p. 35–42.

GS-22

GEOLOGY AND GEOCHEMISTRY OF THE RUTTAN AND DARROL LAKE DEPOSITS (NTS 63B5), MANITOBA

by G.H. Gale, S.H. McClenaghan[1] and R. Yaworski[2]



Gale, G.H., McClenaghan, S.H. and Yaworski, R. 2002: Geology and geochemistry of the Ruttan and Darrol Lake deposits (NTS 63B5), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 198–204.

SUMMARY

Drill cores were logged in detail to establish the stratigraphic position and setting of 'ore equivalent' strata at the Ruttan and Darrol Lake deposits. Alteration mineral assemblages in the Ruttan deposit are extensive and can be used to distinguish crosscutting and stratabound (exhalite) alterations, but are insufficiently understood to establish reliable exhalite strata within the deposit. The drill-core studies have established that rocks previously mapped as 'quartz-feldspar intrusion' are felsic volcaniclastic rocks, thus casting some doubt on the stratigraphic position of the 'important ore equivalent' rocks northeast of the mine. In addition, none of the rocks occurring at the northeastern extremity of the Ruttan mine are rhyolite, but are altered rocks derived, in part, from felsic volcanic rocks, such as rhyolite or dacite, and exhalite (?chert).

Geochemical data from drill cores within an upper Zn-rich zone of the Ruttan mine show REE profiles with well-defined $Eu^d>0$[3] anomalies in both layered sulphides and associated quartz-sericite schist. Preliminary data suggest that positive Eu^d anomalies extend off the end of the deposit for a distance of more than 1 km. In addition, an unexplained $Eu^d>0$ anomaly in drillhole 96-02 occurs approximately 150 m stratigraphically above known mineralization.

The Darrol Lake deposit occurs in a sequence of volcanosedimentary rocks similar to those hosting the Ruttan mine. Sulphide mineralization in this deposit occurs predominantly as veins and veinlets of pyrrhotite and sphalerite at several stratigraphic levels in the sequence. Layered magnetite is present adjacent to the sulphide mineralization in many drill cores. Minerals typically found in alteration zones appear to be predominantly stratabound, and clear evidence of crosscutting footwall-type alteration was not observed. Gahnite, a common constituent of several sulphide-bearing sections, also occurs at different stratigraphic positions within the deposit. Quartz-rich chert-like rocks are rare and occur in only several closely spaced drillholes; semimassive pyrite and chert layers occur together in only one drill core.

INTRODUCTION

Regional setting

The Ruttan and Darrol Lake deposits are located in the Paleoproterozoic Rusty Lake greenstone belt (Fig. GS-22-1). The Rusty Lake belt comprises four structurally bound supracrustal blocks: Karsakuwigamak Block, Northern Block, Eastern Block and Ruttan Block (Baldwin, 1988). The constituent blocks are separated by major faults that truncate the stratigraphy defining the respective blocks. The Ruttan and Darrol Lake deposits are hosted within the westernmost Ruttan Block, which is characterized by a northern south-younging and a southern north-younging supracrustal succession (Baldwin, 1988), separated by the composite Corner Lake pluton (Ames, 1996).

Project description

This project is a continuation of one undertaken in co-operation with the Ruttan mine geology staff to document the rare earth element (REE) geochemistry in and around a massive sulphide deposit. Samples collected from underground workings and surface drill cores in previous years indicated that there are strong Eu depletions ($Eu^d < 0$) in intensely altered rocks and strong Eu enrichment ($Eu^d > 0$) in rocks considered to be the 'ore equivalent' or distal exhalite to the mineralization (cf. Gale et al., 1997).

The unexpected announcement of the Ruttan mine closure required an acceleration of the documentation project while drill core and pulps were still available. An evaluation of available drill core along the northeast extension of the mine was also undertaken to establish if residual exploration potential exists in that part of the property. Drill cores from

---

[1] Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3

[2] Chief Mine Geologist, Hudson Bay Mining and Smelting Co. Ltd., General Delivery, Leaf Rapids, Manitoba R0B 1W0

[3] Eu^d=% deviation chondrite normalized Eu from Eu^* (see Gale et al., 1997)

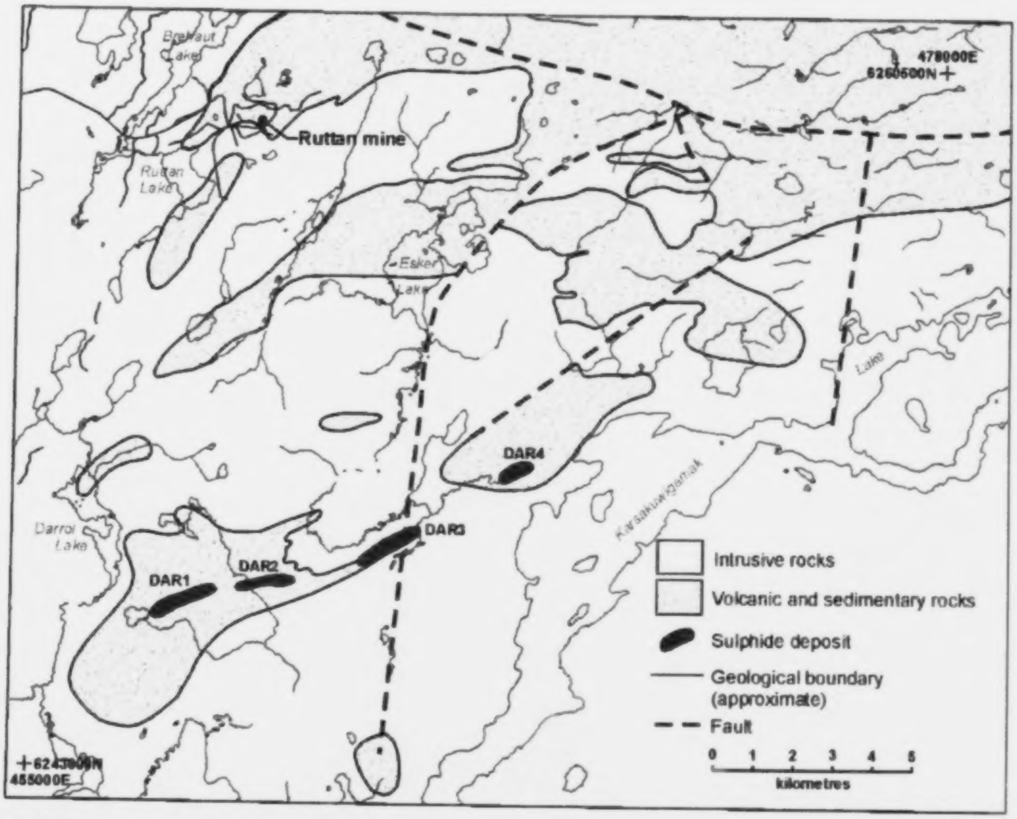


Figure GS-22-1: Location of the Ruttan mine and Darrol Lake deposits.

the northeastern part of the deposit were examined in detail and sampled to establish if distal exhalite could be identified using REE data, and to establish the stratigraphic framework of the previously identified Eu-anomalous samples. These studies will enable a refinement of previously published geological maps and reports (Ames, 1996) and provide a better understanding of the geology and residual potential of the Ruttan area.

The Darrol Lake area, approximately 12 km south of the Ruttan Mine, contains several small, low-grade sulphide deposits (Ferreira, 1994). These deposits have been extensively drilled, but there are few geochemical data available to establish the nature of the mineralization. It has been suggested that the geological setting and mineralization are similar to those of the Ruttan mine. Consequently, cores were relogged and sampled to determine if new insights gained into the geological setting and geochemistry could assist in evaluation of mineral potential in this 10 km long belt of volcanosedimentary rocks with abundant electromagnetic conductors.

GEOLOGY OF THE RUTTAN MINE AREA

The Ruttan volcanogenic massive sulphide (VMS) deposit occurs within a thick sequence of felsic to intermediate volcaniclastic rocks that consist predominantly of volcanic sandstones, but include volcaniclastic rocks with recognizable angular to subrounded rhyolite and basalt fragments 2 to 30 cm in length (Baldwin, 1988; Ames, 1996). The deposit and its altered footwall rocks are separated from the predominantly mafic rocks to the northwest by the North Wall Shear, which is a late, brittle deformation zone that has brought low-sulphide, weakly altered volcaniclastic rocks to the northwest in contact with rusty-weathered, sulphide-rich, intensely altered and mineralized rocks. It appears that rocks on the southeast side of the North Wall Shear are displaced upward.

Speakman et al. (1982) described the deposit in detail. Ames (1996) and Ames and Taylor (1996) reported on the geology of the West Anomaly zinc mineralization and the geochemistry of country rocks and alteration. The oldest rocks recognized in the footwall to the deposit are massive, pillowed and volcaniclastic basalt. These are overlain by Footwall Volcaniclastic rocks and altered Footwall Volcaniclastic rocks that are dacitic to rhyolitic in composition where examined by the authors in the northeastern part of the deposit. These rocks are overlain by the 'Mine Rhyolite', a (?)silicified volcaniclastic rock that hosts the massive sulphide lenses (Speakman et al., 1982). These rocks and the ore lenses are overlain by a 50 m thick unit of chemical and clastic sedimentary rocks referred to as the 'Exhalite Horizon' (Speakman et al., 1982). The Exhalite Horizon is overlain by the Powder Magazine volcaniclastic unit (Speakman et al., 1982; Baldwin, 1988). The present studies and sampling have focused on rocks northeast of the Ruttan mine open pit, including Footwall Volcaniclastic rocks, Exhalite Horizon and Powder Magazine unit, which were also the focus of a study of the 'Ruttan Extension' (Ames, 1996; Ames and Taylor, 1996).

Ruttan sulphide deposit

Drill cores from northeast of the Ruttan open pit were logged to identify marker units and mineralized sections. In general, the oldest rocks observed in drill cores at the eastern end of the Ruttan mine are a thick sequence of visually altered felsic volcaniclastic rocks that occur predominantly northwest of the projected position of the North Wall Shear. These rocks are overlain by a 200 m thick sequence of altered and mineralized rocks that consists of at least three units of exhalite-derived rocks, separated by visually unaltered felsic and intermediate volcanic sandstone and greywacke.

The lowermost of these 'exhalite' units is characterized by quartz-rich rocks, coarse-grained chlorite-biotite schist and minor base metals, whereas the uppermost 'exhalite' unit is characterized by abundant chert, quartz-sericite schist and minor pyrite. These rocks and the associated sulphides constitute the Exhalite Horizon of Speakman et al. (1982), and appear to overlie the low-grade, main, Cu>>Zn sulphide ore bodies, such as the East lens. The uppermost unit of exhalite is probably the stratigraphic equivalent of the hanging wall zinc zones. These high-grade, sphalerite-rich, Zn>>Cu lenses occur in the hanging wall to the main, pyrite-rich, sulphide orebodies, such as the East lens.

The exhalite-bearing rocks are stratigraphically overlain by an approximately 125 m thick unit of well-bedded, felsic to intermediate volcanic sandstone. Locally, the unit contains beds, less than 1 m thick, of mafic and intermediate volcaniclastic rocks, with less than 1 to 10 cm fragments. These rocks occur between the 'exhalite' unit, or mine sequence, and an overlying distinctive unit of layered quartz- and feldspar-bearing, felsic volcaniclastic rocks that also has a thickness of approximately 125 m. These felsic volcaniclastic rocks, where exposed on surface, are well bedded, contain either mafic and felsic fragments or only felsic fragments, and consist of interlayered felsic sandstone and sandstone-supported breccia. The base of the unit, observed in drill core, is chararacterized by quartz crystal–rich, poorly layered sandstone and grit. The central part of the unit is similar to the surface exposures and consists of interlayered felsic sandstone and sandstone with angular 1 to 10 cm fragments; locally, there are quartz-rich and quartz-feldspar–rich beds. The uppermost part of this unit consists of several tens of metres of well-layered felsic sandstone with distinctive 10 to 30 cm thick beds of medium- to coarse-grained, subrounded quartz. The top of the unit is marked by felsic siltstone that is bedded on a millimetre to centimetre scale and has a distinctive brown colour; several of the siltstone beds are characterized by coarse-grained hornblende porphyroblasts.

Although preparation of a final map must await further mapping and analysis of geochemical data, it is possible now to confirm that the felsic volcaniclastic unit is a distinctive marker horizon within the Powder Magazine formation. The upper contact of this unit could easily be confused with that of 'ore equivalent' felsic rocks. It is anticipated that further structural and geochemical studies may assist in refining the northeast extension of the Ruttan mine strata within the Powder Magazine unit (Fig. GS-22-2; cf. Ames [1996], who identified the felsic volcaniclastic unit as a quartz-plagioclase porphyry intrusion).

Stratigraphic tops

Although the Powder Magazine unit has been considered to be a folded homoclinal sequence (Baldwin, 1988; Speakman et al., 1992), there is some concern about whether the present shapes of the ore lenses can be attributed to stacked ore lenses or the result of tight to isoclinal folds and brittle-ductile deformations. Although a number of top reversals defined by graded bedding are present in the hanging wall sedimentary rocks, these reversals occur in debris-flow deposits, where reverse size grading may preclude reliance on graded beds as reliable determination of facing direction. In complexly deformed deposits, the sulphide lens morphology, metal zonation and relationship to alteration can provide reliable criteria for determining stratigraphic tops.

Drillhole UX5730, which was drilled upwards into the structural hanging wall in the East lens, provides a clear definition of stratigraphic tops through sulphide metal zoning, sulphide morphology and position of alteration (Fig. GS-22-3a, GS-22-3b). This hole intersected stringer sulphides in altered quartz-rich rocks in its lower portions, followed upwards by 1) black chlorite schist with abundant chalcopyrite and pyrrhotite vein mobilizate, 2) near-solid pyrite and chalcopyrite, 3) near-solid pyrite and minor sphalerite, 4) near-solid pyrite, 5) pyritic quartz-sericite rock, and 6) quartz-rich rocks derived from chert. This sequence represents a 'classic' alteration and sulphide-chert zonation

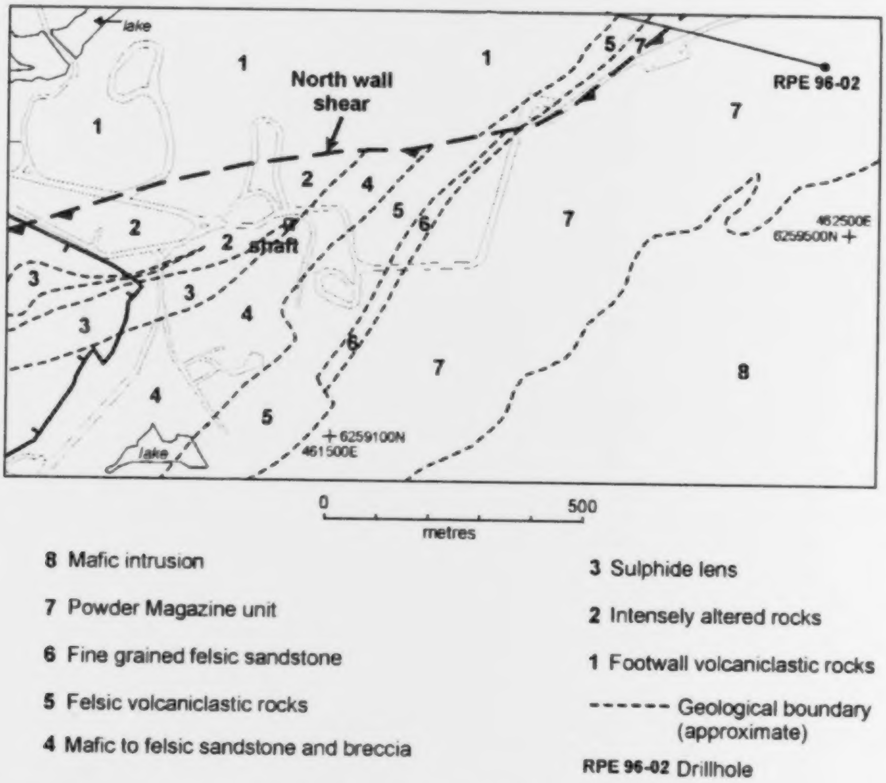

lake
1
North wall shear
RPE 96-02
5
7
2
4
6
shaft
3
8
462500E
6259500N
6259100N
461500E
lake
0
500
metres
8 Mafic intrusion
7 Powder Magazine unit
6 Fine grained felsic sandstone
5 Felsic volcaniclastic rocks
4 Mafic to felsic sandstone and breccia
3 Sulphide lens
2 Intensely altered rocks
1 Footwall volcaniclastic rocks
Geological boundary (approximate)
RPE 96-02 Drillhole

Figure GS-22-2: Geology of the northeast end of the Ruttan mine (modified after Ames, 1996).

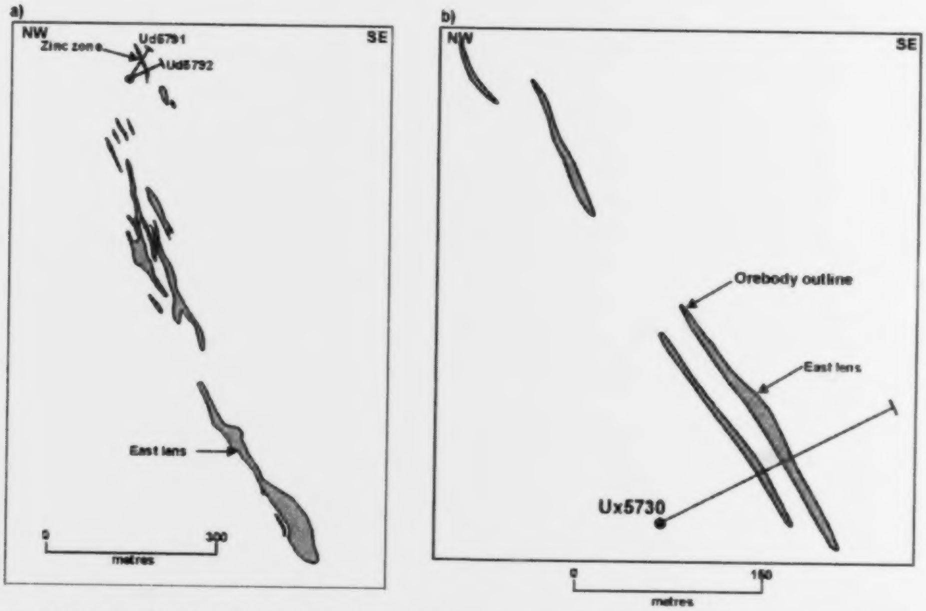

a)
NW
SE
Zinc zone
Ud5791
Ud5792
East lens
0
300
metres
b)
NW
SE
Orebody outline
East lens
Ux5730
0
100
metres

Figure GS-22-3: a) Outline of ore lenses, section 49+00, Ruttan mine. Note relative positions of Zinc zone and East lens. b) Location of drillhole UX5730, projected onto section 57+00E. Note that the ore lens shown is the along-strike continuation of the East lens shown on Figure GS-22-3a.

pattern within a VMS deposit that proceeds from a basal stringer zone to chert. This hole (Fig. GS-22-3b) indicates that this part of the deposit is right side up, and tops in this sulphide zone are towards the structural hanging wall.

Anhydrite, gahnite and staurolite

Several authors have emphasized that the presence of abundant anhydrite at the Ruttan mine has a bearing on deposit genesis and/or should be investigated further (Ames and Taylor, 1996; Barrie and Taylor, 2001). Coarse-grained euhedral anhydrite occurs throughout the deposit in footwall alteration zones, ore zones and hanging wall rocks. It occurs as crystals, up to 20 cm in size, filling tensional fractures and extremely late shear zones in various rock types that postdate folding, metamorphism and intrusion of granite. Although there may be some increase in anhydrite content toward the stratigraphic top of the deposit (Ames and Taylor, 1996), there is also a pronounced increase westward within the mine toward the late, postmetamorphism intrusion. The authors contend that the anhydrite in this deposit is a late mobilizate (Fig. GS-22-4), is clearly related to postmetamorphic events and has no bearing on deposit genesis. It may also be related to late deformation events because it occurs in some shear zones (C.J. Beaumont-Smith, pers. comm., 2002).

Gahnite is commonly observed in the silicate-rich portions of metamorphosed distal exhalite. Gahnite crystals, up to 1 cm in diameter, occur throughout the Ruttan deposit but are most common in quartz-sericite schist, where they clearly overgrow the main foliation. The gahnite also occurs in crosscutting alteration that has recrystallized to chlorite-biotite-cordierite rocks. These crystals, although locally constituting over 10% of the rock, are clearly not restricted to exhalite layers in this deposit and cannot be used as a guide in the delineation of marker units in 'ore equivalent' strata.

Staurolite occurs in altered rocks and exhalite throughout the deposit. It varies in colour from reddish brown to pale yellow, and in crystal habit from euhedral to ragged-edged aggregates. An unusually pale yellow occurrence (Fig. GS-22-5) illustrates the late nature of this mineral, in that it occurs along cleavage planes in quartz-rich sericitic (?exhalite-derived) alteration.

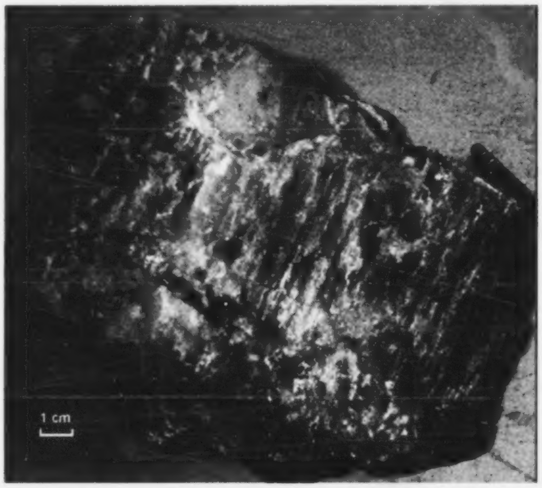


Figure GS-22-4: Typical euhedral anhydrite crystals from a late fracture, Ruttan mine.

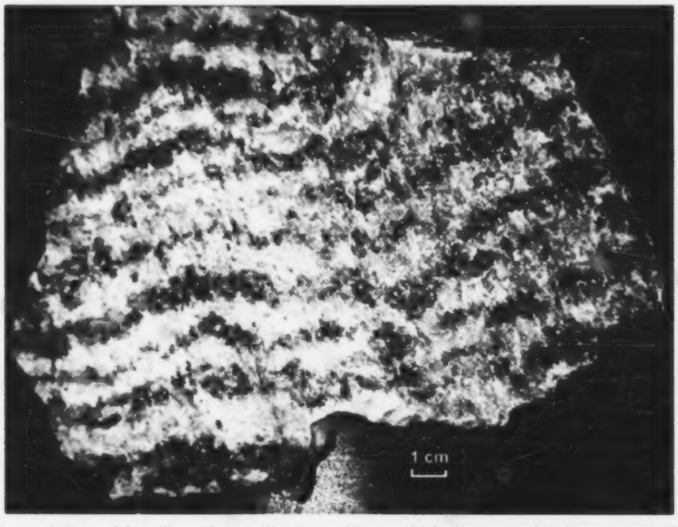


Figure GS-22-5: Quartz-sericite schist alteration with staurolite and biotite growth along early (?)cleavage planes. Photo from Ruttan mine sample collection. Similar rocks are present in footwall alteration zone, structurally below the East lens sulphide orebody.

GEOLOGY OF THE DARROL LAKE DEPOSIT

The sulphide mineralization at Darrol Lake consists of minor pyrrhotite, pyrite, ±sphalerite ±chalcopyrite, in at least four different zones (Dar 1, Dar 2, Dar 3 and Dar 4; Ferreira, 1994) at several different stratigraphic levels along a strike length of approximately 10 km (Fig. GS-22-1). The sulphide zones are delineated by strong electromagnetic conductors. The mineralization at the Dar 2 zone is structurally (and apparently stratigraphically) underlain by rhyolitic volcanic rocks, and overlain by intermediate to mafic volcanosedimentary rocks that are similar to the sandstone portions of the Powder Magazine formation at the Ruttan mine. Rocks in the mineralized zone are dominantly felsic and include felsic sandstone, quartz-sericite schist, quartz-rich intermediate sedimentary rocks and oxide facies iron formation; pelitic and semipelitic rocks with up to 50% phlogopite are present in a number of drill cores. Granitic and pyroxene-rich intrusions are present in both hanging wall and footwall rocks. A number of intersections of pyroxene-rich rocks in the hanging wall sequence have quite variable pyroxene crystal contents that resemble crystal tuff; however, surface exposures have not been examined to determine if there is a volcanic component to these pyroxene-rich rocks.

The Dar 2 deposit contains up to three zones of disseminated and veinlet mineralization within an approximately 60 m thick zone of predominantly felsic (?)sedimentary rocks. Pyrrhotite and sphalerite are the dominant sulphide minerals, but together rarely constitute more than 10 to 20% of the rock. Both occur mainly as sulphide veinlets in conformable to semiconformable zones in association with quartz-rich sericite schist and quartz-rich rocks considered to be chert. Semimassive pyrrhotite, where present, is associated with late deformation zones and the margins of mafic intrusions. Gahnite, a common constituent, is frequently associated with both sericite- and biotite-rich rocks.

Only one drillhole intersected bedded semimassive pyrite, but a number of drillholes intersected intervals of chert several metres thick. None of the drillholes appears to have intersected crosscutting alteration typical of that commonly found underlying VMS-type mineralization. However, several sections of quartz-rich sericite schist and chert-like rocks resemble exhalite-derived material. Consequently, this mineralization is presently considered to represent mobilization of distal exhalite units, deposited from a long-lived mineralized system into late fractures. Geochemical studies are directed at elucidating their geological setting and depositional environments.

RARE EARTH ELEMENT GEOCHEMISTRY OF THE RUTTAN ZINC ZONE

Assay pulps from two drill cores from a hanging wall zinc lens orebody at the Ruttan mine (Fig. GS-22-3) were analyzed to establish if $Eu^d > 0$ values are associated with the Ruttan ores and associated exhalite. The data, presented in Figure GS-22-6, confirm observations from other studies (Gale et al., 1997) that both VMS sulphide ores and their associated exhalite commonly have $Eu^d > 0$. These data provide a basis for further studies and interpretation of exhalite

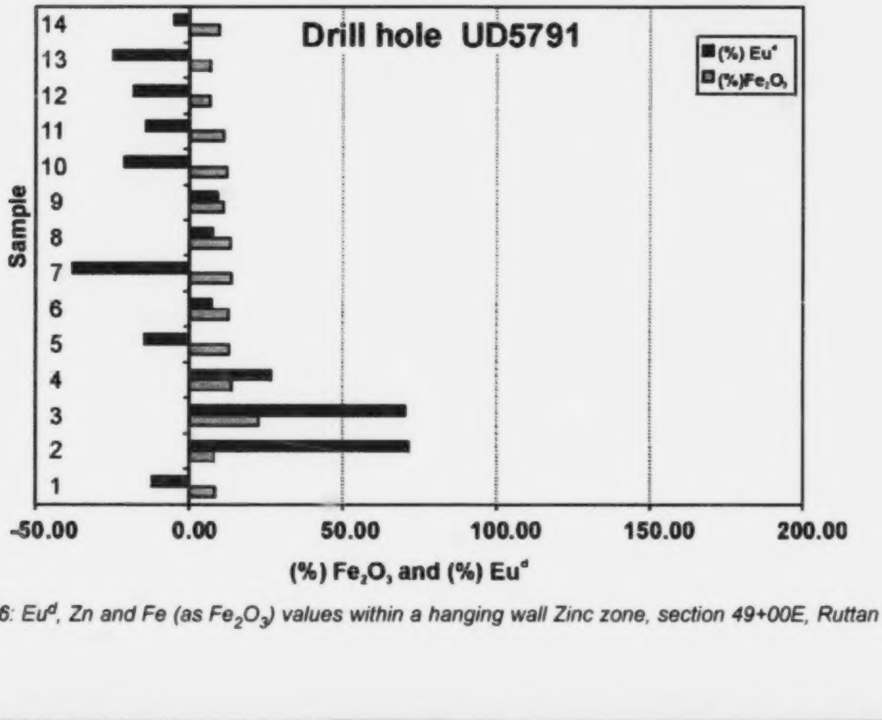


Figure GS-22-6: Eu^d, Zn and Fe (as Fe_2O_3) values within a hanging wall Zinc zone, section 49+00E, Ruttan mine.

distal to the sulphide bodies. They also confirm that the hydrothermal system forming the deposit contained abundant Eu^{+2} ions, which may provide a reliable vector to VMS deposits in this area.

EUROPIUM AS A VECTOR TO THE RUTTAN VMS MINERALIZATION

Preliminary data from grab samples of drill core (RPE 96-02) from northeast of the Ruttan mine headframe indicate the presence of a $Eu^d > 0$ anomaly, approximately 1000 m distal to the deposit, but the stratigraphic position of this exhalite relative to the 'ore equivalent' rocks is uncertain. Drill core from the area between the northeast end of the ore deposit and drillhole RPE 96-02 has been relogged and extensively sampled in order to establish the variability of Eu^d anomalies and their utility in vectoring to further VMS mineralization in this area.

ACKNOWLEDGMENTS

This project was made possible through the co-operation of Hudson Bay Mining and Smelting Co. Ltd. (HBMS). The authors thank the management of HBMS and staff at the Ruttan mine for their assistance and in-kind support. Chris Beaumont-Smith and Alan Bailes kindly reviewed drafts of the manuscript.

REFERENCES

Ames, D.E. 1996: Stratigraphic and tectonic setting of the Paleoproterozoic Ruttan Cu-Zn VHMS deposit, Rusty Lake belt, Trans-Hudson orogen; *in* EXTECH I: A Multidisciplinary Approach to Massive Sulphide Research in the Rusty Lake–Snow Lake Greenstone Belts, Manitoba, G.F. Bonham-Carter, A.G. Galley and G.E.M. Hall (ed.), Geological Survey of Canada, Bulletin 426, p. 15–43.

Ames, D.E. and Taylor, C. 1996: Geology of the West Anomaly orebody, Ruttan volcanic-hosted massive sulphide deposit, Proterozoic Rusty Lake belt; *in* EXTECH I: A Multidisciplinary Approach to Massive Sulphide Research in the Rusty Lake–Snow Lake Greenstone Belts, Manitoba, G.F. Bonham-Carter, A.G. Galley and G.E.M. Hall (ed.), Geological Survey of Canada, Bulletin 426, p. 45–76.

Baldwin, D.A. 1988: Geology of the southern part of the Rusty Lake volcanic belt; Manitoba Energy and Mines, Minerals Division, Geological Report GR86-1, 90 p.

Barrie, C.T. and Taylor, C. 2001: Geology, alteration mineralogy, geochemistry and volcanogenic massive-sulphide potential of the Ruttan mine area and the southern Rusty Lake volcanic belt (NTS 64B); Manitoba Industry Trade and Mines, Manitoba Geological Survey, Open File Report OF2001-9, 25 p.

Ferreira, K.J. 1994: Mineral deposits and occurrences in the Ulhman Lake (south) area, NTS 64B/1 to /8; Manitoba Energy and Mines, Geological Services, Mineral Deposit Series, Report No. 28, 140 p.

Gale, G.H., Dabek, L.B. and Fedikow, M.A.F. 1997: The application of rare earth element analyses in the exploration for volcanogenic massive sulfide type deposits; Exploration and Mining Geology, v. 6, no. 3, p. 233–252.

Speakman, D.S., Chornoby, P.J., Haystead, B.C.W. and Holmes, G.F. 1982: Geology of the X Ruttan deposit, northern Manitoba; *in* Precambrian Sulphide Deposits; R.W. Hutchinson, C.D. Spence and J.M. Franklin (ed.), Geological Association of Canada, Special Paper 25, p. 525–556.

GS-23 DETERMINING RESIDUAL MINERAL POTENTIAL USING EUROPIUM ANOMALIES IN THE RUTTAN AND LYNN LAKE AREAS, MANITOBA

by G.H. Gale and S.H. McClenaghan[1]

Gale, G.H., and S.H. McClenaghan 2002: Determining residual mineral potential using europium anomalies in the Ruttan and Lynn Lake areas, Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 205-208.

SUMMARY

Drill cores from regional exploration programs in the Ruttan and Lynn Lake areas were examined in 2002 for evidence of stratiform sulphide mineralization. In the Ruttan region, these included drill cores that targeted electromagnetic conductors outside the Ruttan mine property. In the Lynn Lake area, only those cores housed in the Lynn Lake Core Library were examined. Cores containing chert, barren sulphides and sulphidic sedimentary rocks were sampled, provided they did not contain significant (>1%) visible base-metal concentrations. Collected samples will be analyzed for major, trace and rare earth elements (REE) to determine if any are spatially associated with more significant base-metal VMS-type mineralization.

INTRODUCTION

Geochemical studies indicate that REE data may be an effective tool to vector base-metal exploration along exhalative sulphide strata (Gale et al.,1997a, b). Unpublished results from studies by the first author indicate that volcanogenic massive sulphide (VMS) vent activity can be readily detected in rocks that contain only background base-metal values at distances of up to 1000 m from known VMS mineralization. In addition, sulphide facies iron formations originating from lower temperature and higher pH fluids than those that produce VMS deposits have distinctly different REE profiles with negative Eu anomalies (Gale et al., 1997a, b).

This program is designed to investigate drill cores from previous, unsuccessful drill programs, to establish if they contain geochemical signatures that may indicate the presence of high-temperature, low-pH vent sites typical of those that produce VMS deposits. Contrasting REE signatures of VMS-related and barren sulphide zones are shown in Figure GS-23-1.

RUTTAN AREA

Drill cores from regional exploration programs conducted outside the immediate Ruttan mine property (Fig. GS-23-2) were examined for evidence of distal exhalite, mineralized sedimentary rocks and footwall alteration mineral assemblages typically associated with VMS mineralization in this area (Gale et al., 1980). In addition, associated host rocks were noted in order to establish the overall geological setting of material sampled.

In general, a number of drill cores intersected volcanosedimentary rocks similar to those identified in cores from the Ruttan mine and the Darrol Lake deposit (Gale and McClenaghan, GS-22, this volume). These volcanosedimentary rocks are characterized by a thick sequence(s) of interlayered, felsic-volcanic–derived sandstone and greywacke containing variable amounts of coarser volcaniclastic rocks, which are together interpreted to be debris flow deposits. In some instances, sulphide mineralization, in places including graphite, occurs in felsic to intermediate volcanosedimentary rocks interlayered with psammitic and semipelitic rocks derived from felsic volcanic source rocks.

Although felsic-volcanic–derived fragmental rocks were intersected in a number of drill cores, flows and autoclastic breccia are rare and felsic agglomerate is not present in any of the cores examined. Of particular interest is the presence of angular fragments of felsic volcanic rocks in a polymictic fragmental rock that resembles 'mill rock' (Fig. GS-23-3). This breccia occurs in a thick sequence of bedded conglomeratic rocks that (?)overlies bedded sulphidic mudstone and felsic volcanic sandstone.

LYNN LAKE AREA

Drill core stored at the Mines Branch core storage facility in Lynn Lake were examined and sampled. A number of cores in this facility contain rocks that resemble exhalite. In addition, several drill cores contain crosscutting alteration veins and trace amounts of base-metal mineralization that signify the presence of VMS-type alteration systems. Samples collected from these cores will be used to determine if the sulphide-producing systems and the magmas generating felsic volcanic rocks were capable of producing base-metal–rich VMS-type fluids.

---

[1] University of New Brunswick, Department of Geology, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3

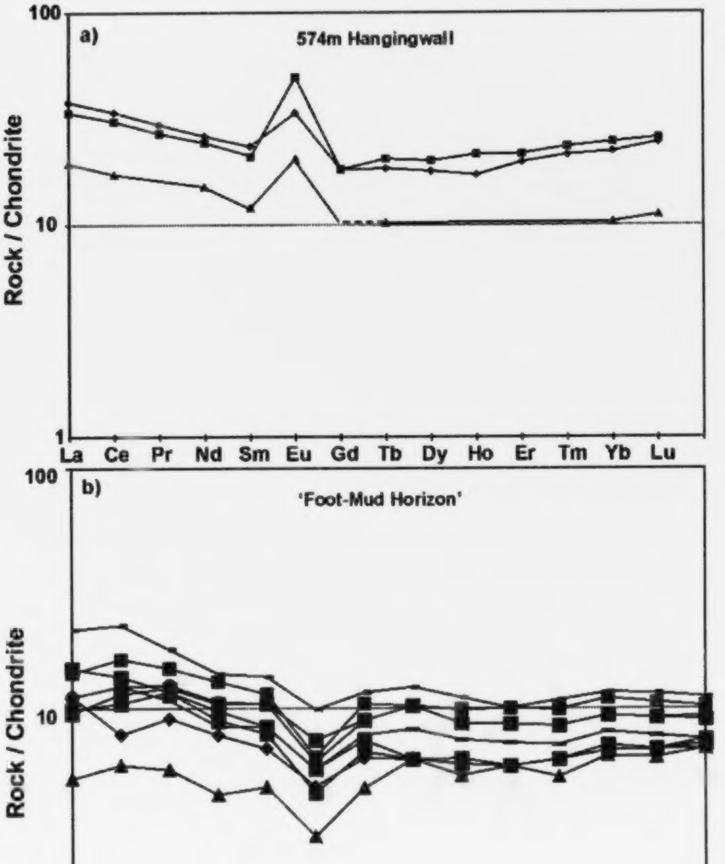


Figure GS-23-1: Rare earth element profiles for: a) a typical distal exhalite related to a massive-sulphide deposit (Spruce Point) and b), c) 'barren' (pyrite-graphite) bedded sulphides.

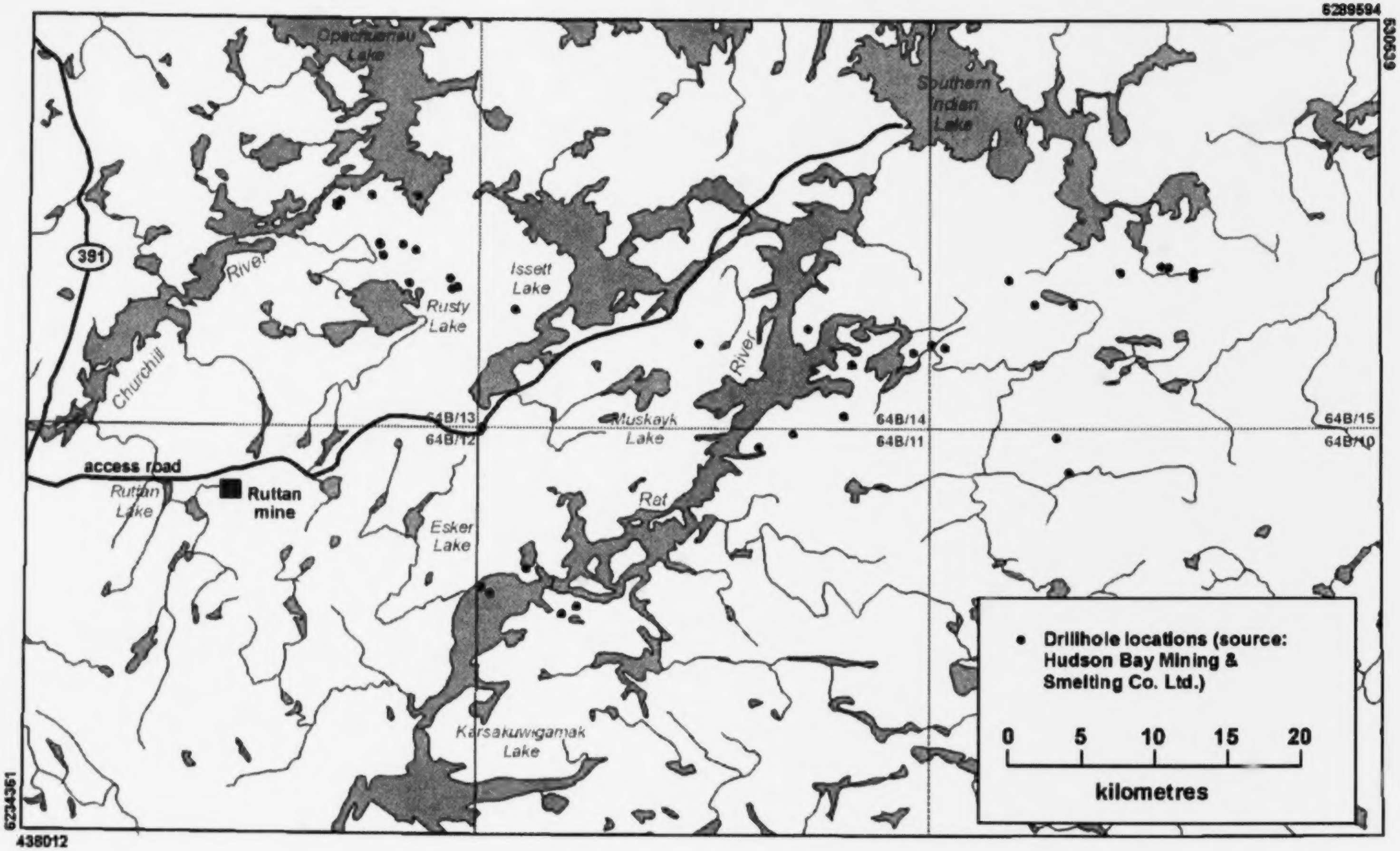

5289594
530539
Opachuanau Lake
Southern Indian Lake
391
River
Churchill
Rusty Lake
Issett Lake
River
Muskayk Lake
Rat
64B/13
64B/12
64B/14
64B/11
64B/15
64B/10
access road
Ruttan Lake
Ruttan mine
Esker Lake
Karsakuwigamak Lake
● Drillhole locations (source: Hudson Bay Mining & Smelting Co. Ltd.)
0
5
10
15
20
kilometres
6234361
438012

Figure GS-23-2: Location of drill cores examined and sampled in the Ruttan area.

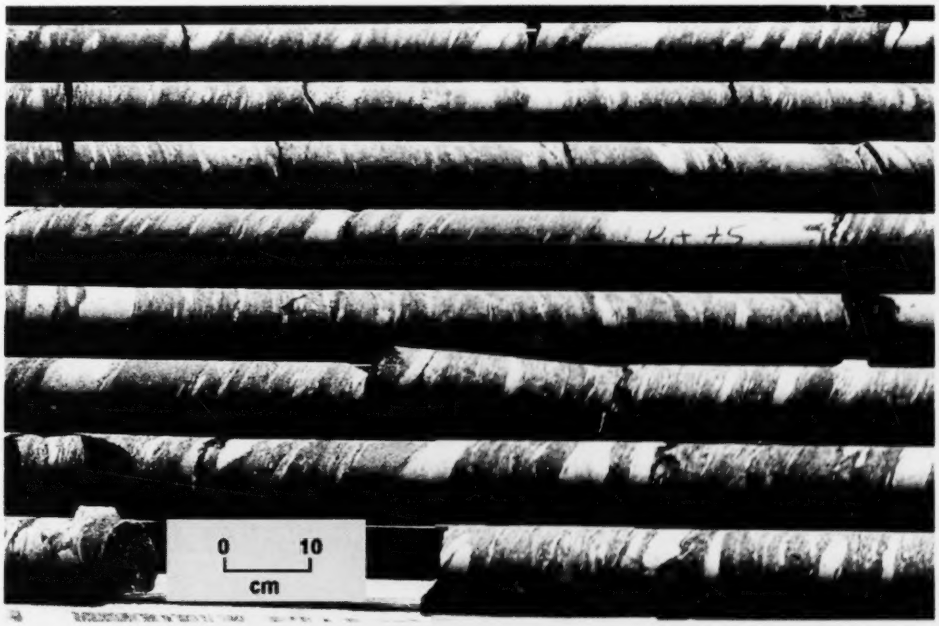


Figure GS-23-3: Angular felsic volcanic fragments in polymictic breccia from drillhole RUT 75. Beds several metres thick are interlayered with possible debris flows.

CONCLUSION

Visual examination of drill cores from the Ruttan region indicates that volcanosedimentary rocks (derived from felsic volcanic rocks), coarse felsic volcaniclastic rocks and chemical sedimentary rocks similar to those found at the Ruttan and Darrol Lake deposits are present at several sites well beyond the known deposits. Although the 'mine strata' has not been positively identified outside the immediate vicinity of the two known deposits, it is the authors' contention that this is a result of a paucity of detailed geological data for the 'Ruttan volcanosedimentary basin'.

The presence of distal exhalite, crosscutting alteration and metalliferous sedimentary rocks in association with felsic volcanic sequences in the Lynn Lake area indicates that this area has the potential to contain additional VMS deposits.

Approximately 300 samples were collected from drill cores from the Ruttan and Lynn Lake areas. All sample information and analytical results will be made available in a database format for ease of retrieval by interested parties.

ACKNOWLEDGMENTS

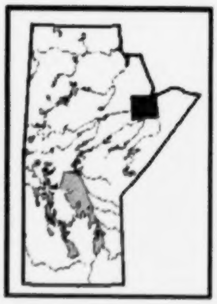
Bob Cooper and Reg Yaworski of HBMS are thanked for their assistance and many considerations during the fieldwork. Jennifer Greville assisted in sample collection and documentation during the latter part of the fieldwork.

REFERENCES

Gale, G.H., Dabek, L.B. and Fedikow, M.A.F. 1997a: The application of rare earth element analyses in the exploration for volcanogenic massive sulfide type deposits; Exploration and Mining Geology, v. 6, no 3, p. 233–252.

Gale, G.H., Dabek, L.B. and Fedikow, M.A.F. 1997b: The use of rare earth element analyses in the exploration for massive sulphide type deposits in volcanic rocks – progress report; *in* Report of Activities 1997, Manitoba Energy and Mines, Geological Services, p. 47–55.

Gale, G.H., Baldwin, D.A. and Koo, J. 1980: A geological evaluation of Precambrian massive sulphide deposit potential in Manitoba; Manitoba Department of Energy and Mines, Mineral Resources Division, Economic Geology Report ER79-1, 137 p.



GS-24 QUATERNARY STRATIGRAPHY AND ICE-FLOW HISTORY ALONG THE LOWER NELSON, HAYES, GODS AND PENNYCUTAWAY RIVERS AND IMPLICATIONS FOR DIAMOND EXPLORATION IN NORTHEASTERN MANITOBA

by E. Nielsen

Nielsen, E. 2002: Quaternary stratigraphy and ice-flow history along the Lower Nelson, Hayes, Gods and Pennycutaway rivers and implications for diamond exploration in northeastern Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 209-215.

SUMMARY

During the 2002 field season, 144 till and 3 alluvial sand and gravel samples were collected from 17 sections exposed in river cuts in the Hudson Bay Lowland of northeastern Manitoba. The 2002 survey was undertaken to outline the Quaternary stratigraphy and determine the ice-flow history and till provenance in the Hudson Bay Lowland of Manitoba in support of diamond exploration. Specifically, the 2002 survey was undertaken as a follow up to the 2001 survey immediately to the south of this area. The 2001 survey suggested that kimberlite indicator minerals were concentrated in Long Spruce till of northern provenance. The objectives of the 2002 survey will be met using a combination of pebble analysis, carbonate analysis, matrix geochemistry, textural analysis, kimberlite indicator-mineral analysis and pebble-fabric analysis.

Preliminary interpretation of the till fabric data suggests the lower part of the Long Spruce till was deposited by ice flow towards the southwest whereas the upper part of the Long Spruce till was deposited by south-southeasterly ice flow. The overlying Sky Pilot till, which forms the surface till throughout northeastern Manitoba, was deposited by southwesterly ice flow.

INTRODUCTION

Quaternary sections in the Hudson Bay Lowland of northeastern Manitoba expose multiple tills, interglacial sediments and a variety of postglacial sediments, including glaciofluvial sand and gravel, glaciolacustrine silt and clay, marine silt and clay, and Holocene fluvial sand and gravel. The oldest till in the Hudson Bay Lowland of Manitoba, the Sundance till, was deposited by ice flow towards the southeast. The next oldest till, the Amery till, is attributed variously to southeasterly and southwesterly ice flow, based on pebble-fabric measurements (Nielsen et al., 1986; Nielsen and Fedikow, 2002). Amery till is overlain by interglacial Nelson River sediments. Nelson River sediments and Amery till are stratigraphically overlain by Long Spruce till deposited by south-southwesterly ice flow. Sky Pilot till, the youngest till in the area, outcrops at the surface throughout northeastern Manitoba. Pebble fabrics of Sky Pilot till indicate southwesterly ice flow.

In the 2001 kimberlite indicator-mineral survey of seven Quaternary sections in the northern Superior Province and adjacent Hudson Bay Lowland, 21 kimberlite indicator minerals (KIM) were recovered from the 69 till and 2 gravel samples (Nielsen and Fedikow, 2002). The 18 Amery till samples from that survey produced no KIM. The 17 Long Spruce till samples contained 14 KIM, whereas the 34 Sky Pilot till samples contained only 2 KIM. The two Holocene gravel samples contained 5 KIM. KIM were concentrated in Long Spruce till and were probably derived from unknown source(s) to the north or north-northeast. The source(s) of KIM may be an unknown bedrock source or an older buried glacial dispersion or preglacial alluvial dispersion train. The KIM in the Sky Pilot till and Holocene gravel samples have been reworked from the underlying Long Spruce till (Nielsen and Fedikow, 2002).

OBJECTIVES

Fieldwork in the summer of 2002 was undertaken to the north of the 2001 survey area (Fig. GS-24-1) to

1) test the conclusion that KIM are concentrated in the Long Spruce till;
2) more precisely determine the provenance of the Long Spruce till;
3) determine the source(s) of KIM detected in the 2001 survey; and
4) obtain additional information on the Quaternary stratigraphy and kimberlite indicator mineral distribution in the Hudson Bay Lowland and adjacent areas of northeastern Manitoba.

The objectives of the survey will be met using a combination of pebble analysis, carbonate analysis, matrix geochemistry, textural analysis, kimberlite indicator-mineral analysis and pebble-fabric analysis.

METHODS

Helicopter-supported fieldwork was undertaken during a four-week period in July using Gillam as the central

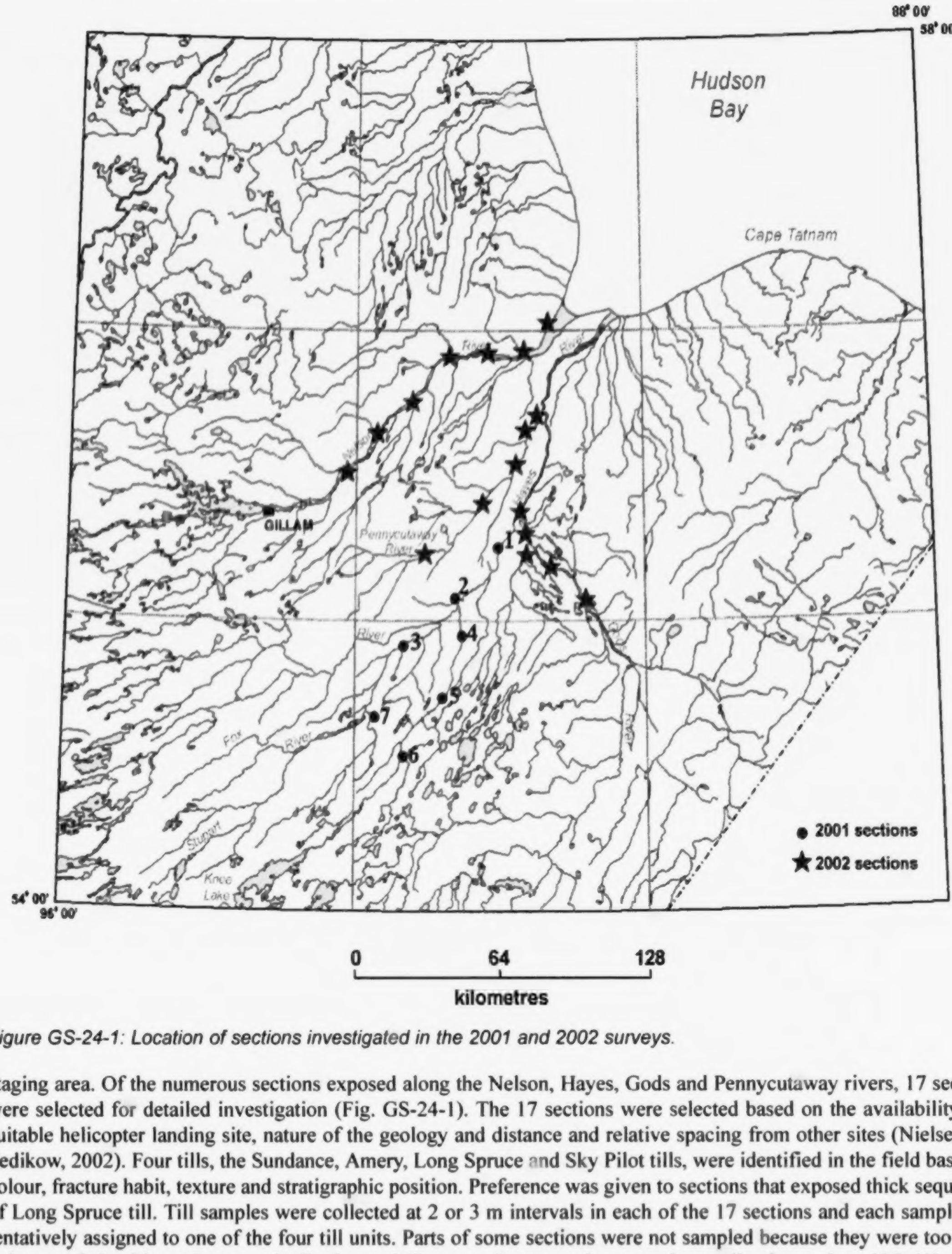

88° 00'
58° 00'
Hudson Bay
Cape Tatnam
River
River
Nelson
Hayes
GILLAM
Pennycutaway River
1
2
3
4
5
6
7
River
Fox River
Stupart
Knee Lake
Gods River
● 2001 sections
★ 2002 sections
54° 00'
96° 00'
0
64
128
kilometres

Figure GS-24-1: Location of sections investigated in the 2001 and 2002 surveys.

staging area. Of the numerous sections exposed along the Nelson, Hayes, Gods and Pennycutaway rivers, 17 sections were selected for detailed investigation (Fig. GS-24-1). The 17 sections were selected based on the availability of a suitable helicopter landing site, nature of the geology and distance and relative spacing from other sites (Nielsen and Fedikow, 2002). Four tills, the Sundance, Amery, Long Spruce and Sky Pilot tills, were identified in the field based on colour, fracture habit, texture and stratigraphic position. Preference was given to sections that exposed thick sequences of Long Spruce till. Till samples were collected at 2 or 3 m intervals in each of the 17 sections and each sample was tentatively assigned to one of the four till units. Parts of some sections were not sampled because they were too steep to be sampled safely or they were badly slumped. Two samples were taken at each sampling interval; an 11 L (40–45 lb) sample was taken for kimberlite indicator-mineral and gravel analysis, and a 2 kg sample was collected for geochemistry. A total of 144 till and 3 gravel samples were collected for analyses from the 17 sites. Pebble fabrics, consisting of 30 clasts each, were measured at 42 sites. Time did not permit fabrics to be measured in section J.

De Beers Exploration Canada Inc. has again extended their offer to concentrate, pick and analyze by electron microprobe the diamond indicator minerals free of charge. In keeping with our usual confidentiality practice, the sample numbers and site locations are not shown in the accompanying figures. The sections have been randomly labelled A through Q for the purpose of the present discussion. Calcite and dolomite content will be determined at the laboratories of the Geological Survey of Canada in Ottawa. Pebble counts, textural analysis and geochemical analysis will be contracted out.

RESULTS

The 17 stratigraphic logs measured in the field are shown in Figure GS-24-2. In places, the sections are capped by a variety of nonglacial sediments including fluvial sand and gravel, Lake Agassiz silt and clay, fine-textured, fossiliferous, Tyrrell Sea marine sediments or Holocene fluvial sediments. These interesting, and in places, complex late glacial and Holocene sediments are not relevant to the present discussion of kimberlite indicator minerals and will not be discussed further. Four tills, Sundance, Amery, Long Spruce and Sky Pilot tills, were identified in the field based on colour, fracture habit, texture and stratigraphic position.

Organic-rich, Nelson River sediments attributed to the Sangamonian interglacial were encountered in sections B, J and O (Fig. GS-24-2). The till below the Nelson River sediments was assigned to the Amery till and the overlying till was assigned to the Long Spruce till. Sections without exposed Nelson River sediments probably comprise only the upper part of the till stratigraphy, namely Long Spruce and/or Sky Pilot tills. This assumption is probably correct if the tills consist of yellowish brown till (Sky Pilot till) overlying dark greyish brown to olive-grey till (Long Spruce till). The presence of subglacial sand and gravel interbeds in sections D, I, M and O is open to interpretation. Paleocurrent directions towards 35° in the sand and gravel at the base of section P indicates these sediments were deposited under non-glacial conditions when Hudson Bay was free of glacial ice. For this reason the sand and gravel unit at the base of this section is assigned to the Nelson River sediments. This interpretation is consistent with the assignment of the overlying tills to Long Spruce and Sky Pilot tills. As paleocurrent directions are not always obtainable and because sand and gravel beds are know to be deposited subglacially, the interpretation of the origin of these beds can be problematic. For this reason the presence of sandy interbeds often adds little to the assignment of age to the tills.

Striations

Striated boulders and striated bedrock surfaces were encountered at only three sites. Striae trending 140° on the Paleozoic bedrock at the base of section J confirm the assignment of the sandy overlying till as Sundance till of northwestern provenance. Striae trending 225° on a boulder pavement at the base of the upper till in section N confirm the overlying brown to dark brown till at this site is Sky Pilot till (Fig. GS-24-3A). A poorly exposed bedrock surface at the base of section M show striae oriented towards 160° or possibly 340° (Fig. GS-24-3B). This orientation is consistent with the pebble fabric of the overlying Long Spruce till though the contact is not exposed.

Till Fabrics

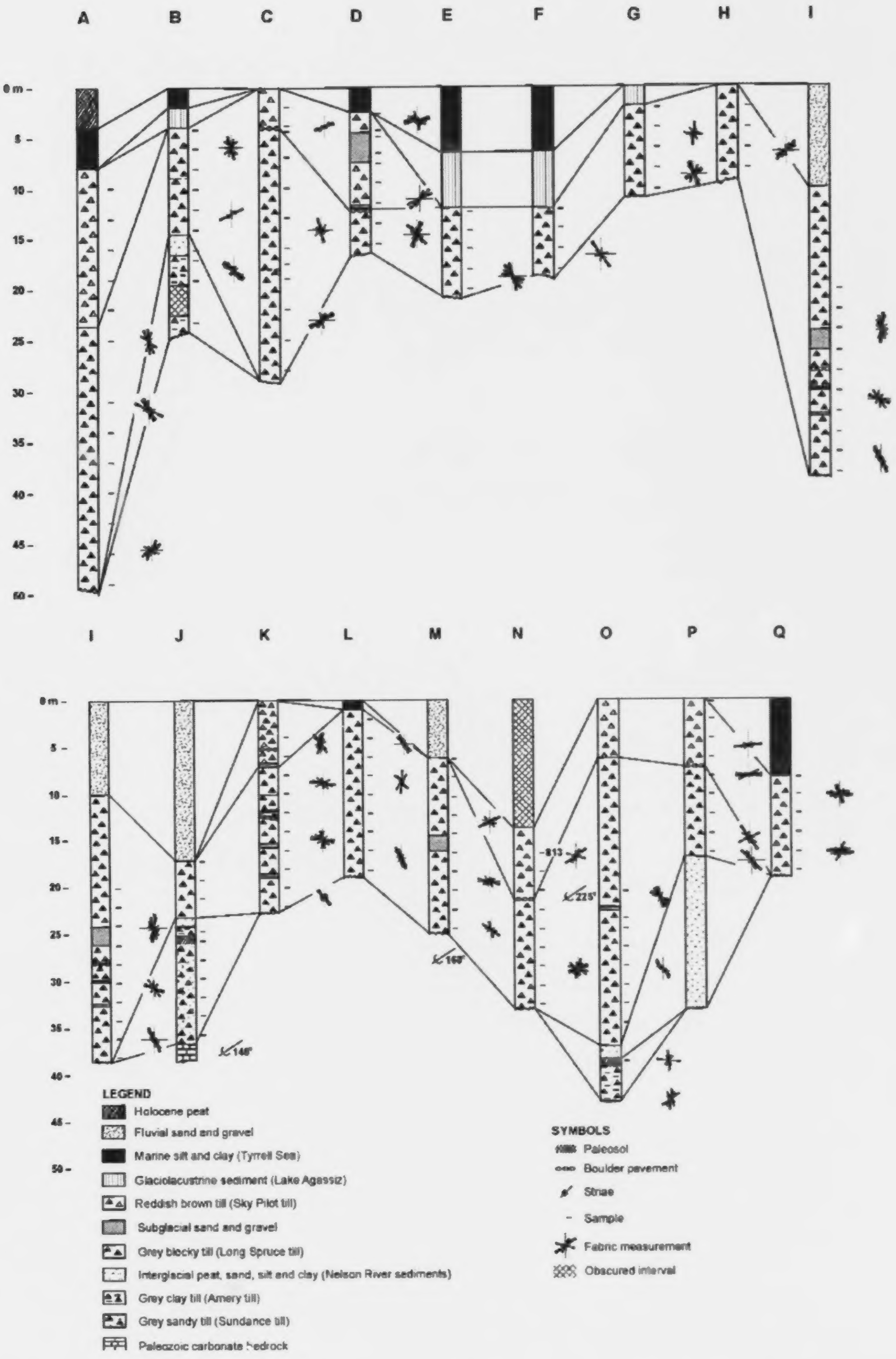
Amery till

Pebble fabrics were measured in the Amery till in sections B and O (Fig. GS-24-2). In section B the fabric was measured 1.5 m below the contact with the overlying Nelson River sediments and shows a strong pebble alignment towards the southeast (137°). Two fabrics, 0.5 m and 3.0 m below the overlying Nelson River sediments, were measured in section O. The upper fabric, being too close to the surface and possibly affected by frost and other near-surface processes, is inconclusive and was disregarded. The fabric at the 3.0 m level should be deep enough so as not to have been affected by near-surface processes during the Sangamonian. This fabric shows ice flow towards approximately 195°. The variable fabrics of the Amery till is consistent with the findings in the 2001 survey (Nielsen and Fedikow, 2002), but clearly more sections must be investigated to get a clear understanding of the changing ice-flow trajectory and provenance of the Amery till.

Long Spruce till

The Long Spruce till, as interpreted in the field, is exposed in every section except section Q (Fig. GS-24-2). Fabrics were measured at 30 sites in the Long Spruce till and a duplicate fabric was measured at the base of section P to test the reproducibility of the technique.

Long Spruce till fabrics measured near the base of sections A, B, C, H, M, N and P in the 2002 survey and from two sites in the 2001 survey are oriented towards the southwest (Fig. GS-24-4a). Fabrics at higher levels in sections A, B, C, D, E, F, G, I, K, L, O and P from the 2002 survey and three sites from the 2001 survey are oriented more towards the southeast (Fig. GS-24-4b). Sections E, F, G, I, K, L, M and O show a southeasterly or a southerly and southeasterly



A
B
C
D
E
F
G
H
I
0 m
5
10
15
20
25
30
35
40
45
50
I
J
K
L
M
N
O
P
Q
-813
225°
160°
140°
LEGEND
Holocene peat
Fluvial sand and gravel
Marine silt and clay (Tyrrell Sea)
Glaciolacustrine sediment (Lake Agassiz)
Reddish brown till (Sky Pilot till)
Subglacial sand and gravel
Grey blocky till (Long Spruce till)
Interglacial peat, sand, silt and clay (Nelson River sediments)
Grey clay till (Amery till)
Grey sandy till (Sundance till)
Paleozoic carbonate bedrock
SYMBOLS
Paleosol
Boulder pavement
Striae
Sample
Fabric measurement
Obscured interval

Figure GS-24-2: Stratigraphic logs measured along the Nelson, Pennycutaway, Gods and Hayes rivers.

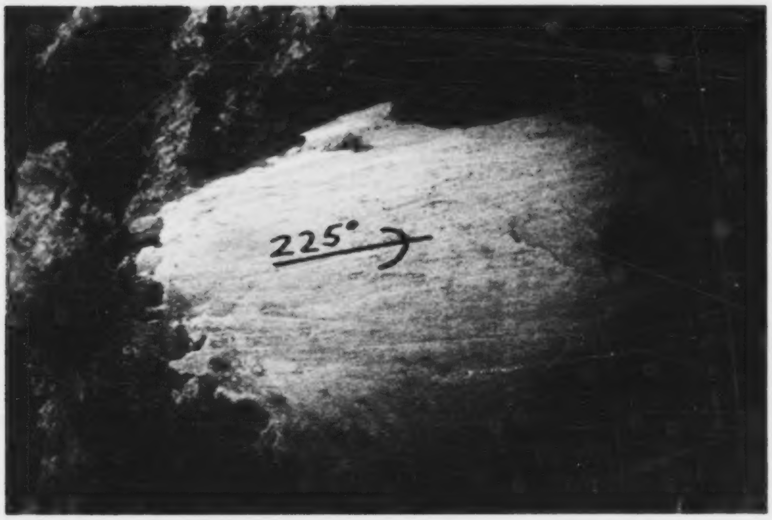


Figure GS-24-3A: Striated boulder pavement at the base of the Sky Pilot till in section N.

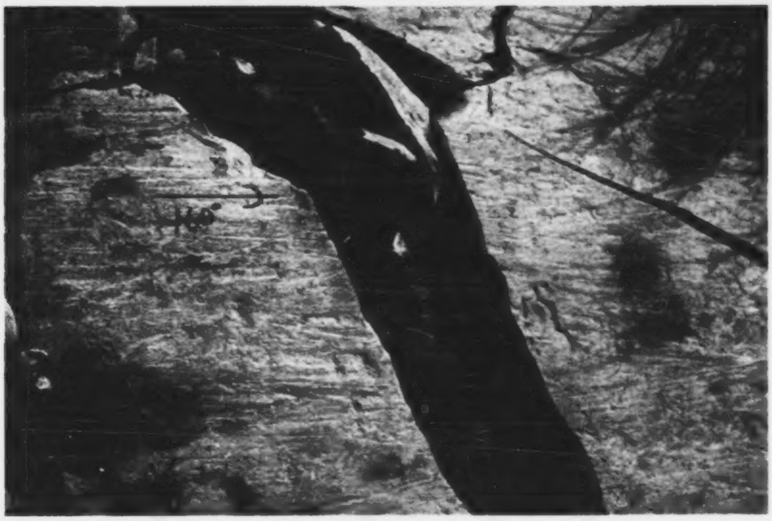


Figure GS-24-3B: Striated bedrock at the base of section M.

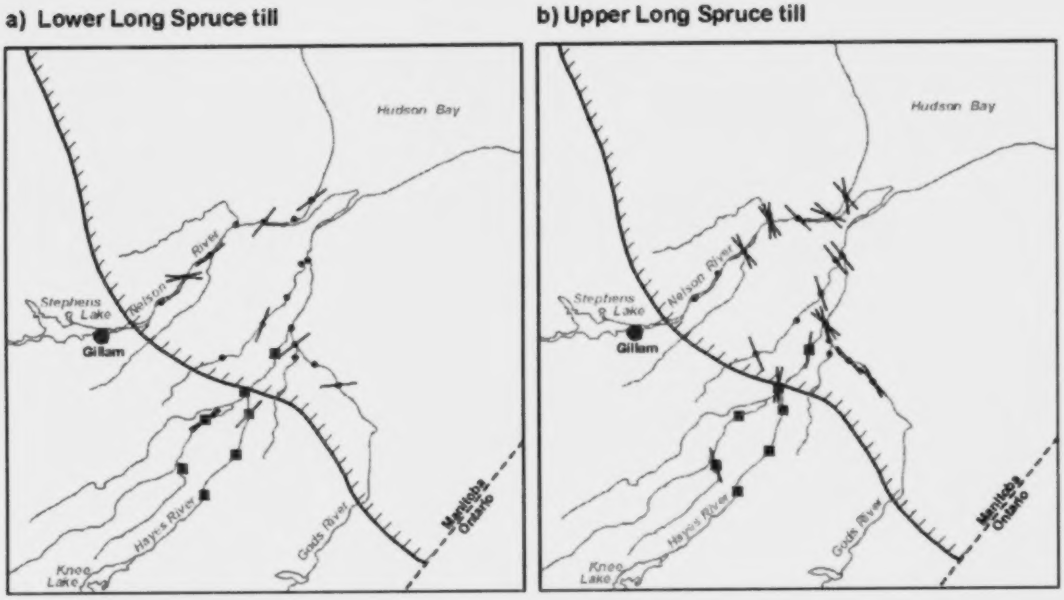
pebble fabric and are interpreted to represent only the upper part of the Long Spruce till sequence (Fig. GS-24-4b). The westerly oriented fabric near the top of the Long Spruce till in section P is probably the result of reorientation of the pebbles by overriding ice, which deposited the Sky Pilot till. Care should be taken so as not to measure till fabrics too close to major stratigraphic boundaries as has happened in this case. The fabric near the base of section N appears random and was disregarded. Other fabrics such as the Long Spruce fabric at the base of sections D and G are bimodal and must be interpreted with care.

The change in the fabrics from southwesterly near the base of the Long Spruce till to more southeasterly towards the top of the sequence indicate the ice-flow trajectory changed from southwest to southeast during deposition of the till (Fig. GS-24-4a, GS-24-4b). This conclusion highlights the need for measuring multiple till fabrics from numerous sections before a clear understanding of the ice-flow history can be obtained.

Sky Pilot till

Till fabrics measured in Sky Pilot till in sections C, D, K, N, P and Q from the 2002 survey (Fig. GS-24-2) and one site from the 2001 survey trend west-southwest and west (Fig. GS-24-4c), and are subparallel to the orientation of drumlins, eskers and striations in the Hudson Bay Lowland and adjacent parts of the northern Superior Province (Nielsen et al., 1986; Fedikow et al., 2002).

The fabric in section K is bimodal and the orientation is unlike that of the other Sky Pilot fabrics. This fabric is

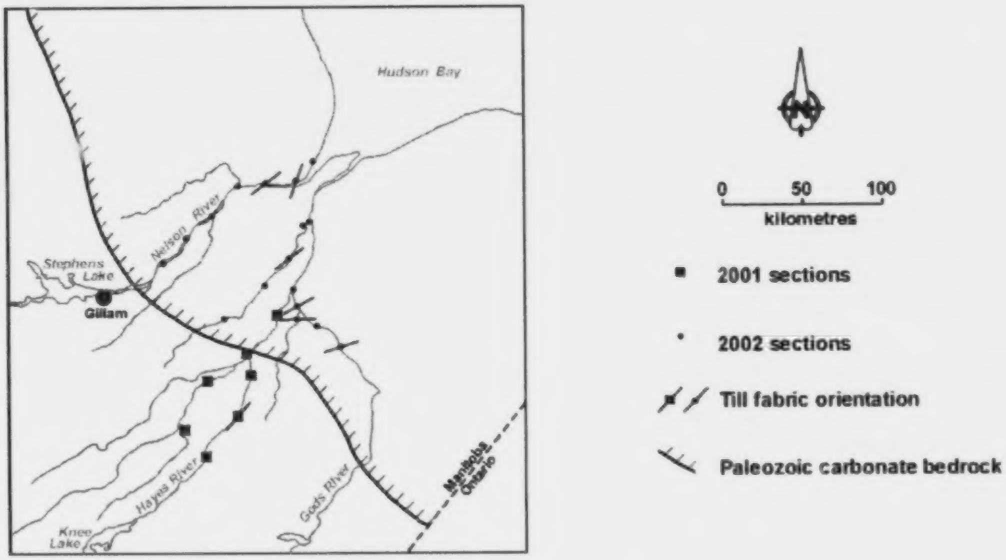


a) Lower Long Spruce till

b) Upper Long Spruce till

Hudson Bay
Nelson River
Stephens Lake
Gillam
Hayes River
Gods River
Knee Lake
Manitoba
Ontario

c) Sky Pilot till



Hudson Bay
Nelson River
Stephens Lake
Gillam
Hayes River
Gods River
Knee Lake
Manitoba
Ontario
0
50
100
kilometres
2001 sections
2002 sections
Till fabric orientation
Paleozoic carbonate bedrock

Figure GS-24-4: a) Southwesterly oriented till fabrics in the lower part of the Long Spruce till. b) Southeasterly oriented till fabrics in the upper part of the Long Spruce till. c) Southwesterly oriented till fabrics in the Sky Pilot till.

similar to the upper till fabric in section B, which was tentatively assigned to the Long Spruce till based on the colour and similarity of the fabric to the top fabric in section A. The sandy texture and brown colour of the upper till in section K may indicate a more locally derived facies not representative of Sky Pilot till.

CONCLUSION

Two till fabrics, measured in two sections, indicate Amery till was deposited by ice flowing first towards the southeast and then the southwest.

Based on the analysis of 30 till fabrics measured in 16 sections, Long Spruce till was deposited by ice flowing towards the southwest and then changing trajectory to the south and southeast.

Sky Pilot till was deposited by southwesterly and westerly ice flow as recorded by 8 fabrics measured in 6 sections.

Clearly the ice-flow trajectory during the deposition of each till was variable in both time and space and many till fabric sites are necessary to obtain a clear understanding of the provenance of the resultant till(s). In addition to field relations, till fabric and colour determinations, compositional data such as pebble counts and trace-element geochemistry may help determine the provenance of tills in areas with complex glacial stratigraphies and few ice-flow directional indicators. Only when the sequences of ice-flow events, ice-flow directions and approximate glacial transport distances are known, can the source(s) of KIM in the Hudson Bay Lowland of Manitoba be located.

ACKNOWLEDGEMENTS

C. Bater and R. Oger were again able and enthusiastic field assistants and the author is indebted to them for their hard work and geological insights throughout the summer. The author also wishes to thank our helicopter pilots, A. Dejardins and J. Gibson, Provincial Helicopters Ltd. (Lac du Bonnet), for their considerable skill and good judgement in piloting us safely.

REFERENCES

Fedikow, M.A.F., Nielsen, E., Conley, G.G. and Lenton, P.G. 2002: Operation Superior: multimedia geochemical survey results from the northern half of the Knee Lake greenstone belt, northern Superior Province, Manitoba (NTS 53L); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Open File Report OF2001-1, 563 p. in 2 volumes plus 1 CD-ROM.

Nielsen, E. and Fedikow, M.A.F. 2002: Kimberlite indicator-mineral survey, lower Hayes River; Manitoba Industry and Mines, Manitoba Geological Survey, Geoscientific Paper GP2002-1, 39 p.

Nielsen, E., Morgan, A.V., Morgan, A., Mott, R.J., Rutter, N.W. and Causse, C. 1986: Stratigraphy, paleoecology, and glacial history of the Gillam area, Manitoba; Canadian Journal of Earth Sciences, v. 23, p. 1641–1661.

GS-25 TECTONOSTRATIGRAPHIC PANELS AND EARLY DEFORMATION IN THE ISLAND LAKE GREENSTONE BELT (NTS 53E15 AND 16), NORTHWESTERN SUPERIOR PROVINCE, MANITOBA

by J. Parks[1], S. Lin[1], M.T. Corkery, K.Y. Tomlinson[2] and D.W. Davis[3]

Parks, J., Lin, S., Corkery, M.T., Tomlinson, K.Y. and Davis, D.W. 2002: Tectonostratigraphic panels and early deformation in the Island Lake greenstone belt (53E15 and 16), northwestern Superior Province, Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 216–225.

SUMMARY

The Island Lake greenstone belt is composed of the volcanic and volcanogenic sedimentary rocks of the Hayes River Group and sedimentary rocks of the Island Lake Group, all of which are intruded by various plutons. Field mapping, geochemical and geochronological work demonstrate that the Hayes River Group consists of lithologically, geochemically and chronologically distinct panels, and that at least three distinct volcanic episodes are recorded in this greenstone belt, at ca. 2852 Ma, ca. 2744 Ma and ca. 2730 Ma. New mapping also led to the elucidation of the geometry of folding and the recognition of a stratigraphy in the panel south of the Savage Island Shear Zone.

INTRODUCTION

The Island Lake greenstone belt is one of the best exposed, continuous greenstone belts in the northwestern Superior Province. The aim of this study is to better understand the depositional, structural, volcanic and regional tectonic history of this belt. A nine-week field program was conducted in each of the summers of 2001 and 2002 to supplement previous mapping in the greenstone belt and to collect samples for geochemical, isotopic and geochronological analysis. Results from mapping and preliminary geochemical and geochronology data are presented in this report, along with a recalculation of the Nd isotope data of Stevenson and Turek (1992) using new geochronological results presented here and in Parks et al. (2001). Also presented is a new structural interpretation for the Jubilee Island area, which was an area of focus during fieldwork completed this summer.

The Island Lake greenstone belt was mapped at a scale of 1:63 360 by Godard (1963 a, b) and at 1:20 000 by Neale (1981), Neale and Weber (1981), McGregor and Weber (1982), Neale et al. (1982), Weber et al. (1982a, b), Gilbert et al. (1982, 1983) and Gilbert (1984a, b, 1985a, b). A Nd isotope study was carried out by Stevenson and Turek (1992), and U-Pb geochronology was conducted by Turek et al. (1986) and Corfu and Lin (2000). The geology of mineral occurrences has been described by Theyer (1998), Lin and Cameron (1997) and Lin and Corfu (2002). The current study is, in part, a continuation of the work started by Lin et al. (1998), Corfu and Lin (2000) and Parks et al. (2001).

GEOLOGICAL SETTING

The Island Lake greenstone belt is part of the Island Lake Terrane and is flanked to the south by the ca. 3.0 Ga crust of the North Caribou Terrane and to the north by the less than 2.86 Ga Munro Lake Terrane (Thurston et al., 1991). The North Caribou Terrane represents an old protocratonic nucleus that occupies a large part of the northwestern Superior Province and acted as a stable platform to which other terranes were subsequently accreted (Thurston et al., 1991). The Munro Lake Terrane is interpreted to represent a younger than 2.86 Ga rift sequence that was built on the reworked northern margin of the North Caribou Terrane (Skulski et al., 2000). The Island Lake Terrane (defined as greater than 2886 Ma by Thurston et al., 1991) was considered to be a separate terrane from the North Caribou and Munro Lake terranes because it has a unique geological history and is slightly younger than the North Caribou Terrane and slightly older than the Munro Lake Terrane. New geochronology and isotopic work is redefining the age and nature of the Island Lake Terrane, and therefore its importance in the tectonic evolution of the northwestern Superior Province.

The Island Lake greenstone belt (Fig. GS-25-1) is variably metamorphosed from greenschist to lower amphibolite facies. It has traditionally been divided into two groups: the younger sedimentary rocks of the Island Lake Group (ILG), which unconformably overlie the dominantly volcanic rocks of the Hayes River Group (HRG). In addition, the central part of the greenstone belt is intruded by the extensive ca. 2744 Ma Bella Lake pluton (Corfu and Lin, 2000). The present study and the work of Corfu and Lin (2000) have shown, however, that the Hayes River Group consists of five geochemically and geochronologically distinct tectonostratigraphic panels that are separated by shear zones. These

---

[1] Department of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1

[2] Department of Geology, University of Toronto, Toronto, Ontario M5S 3B1

[3] Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario M5S 2C6

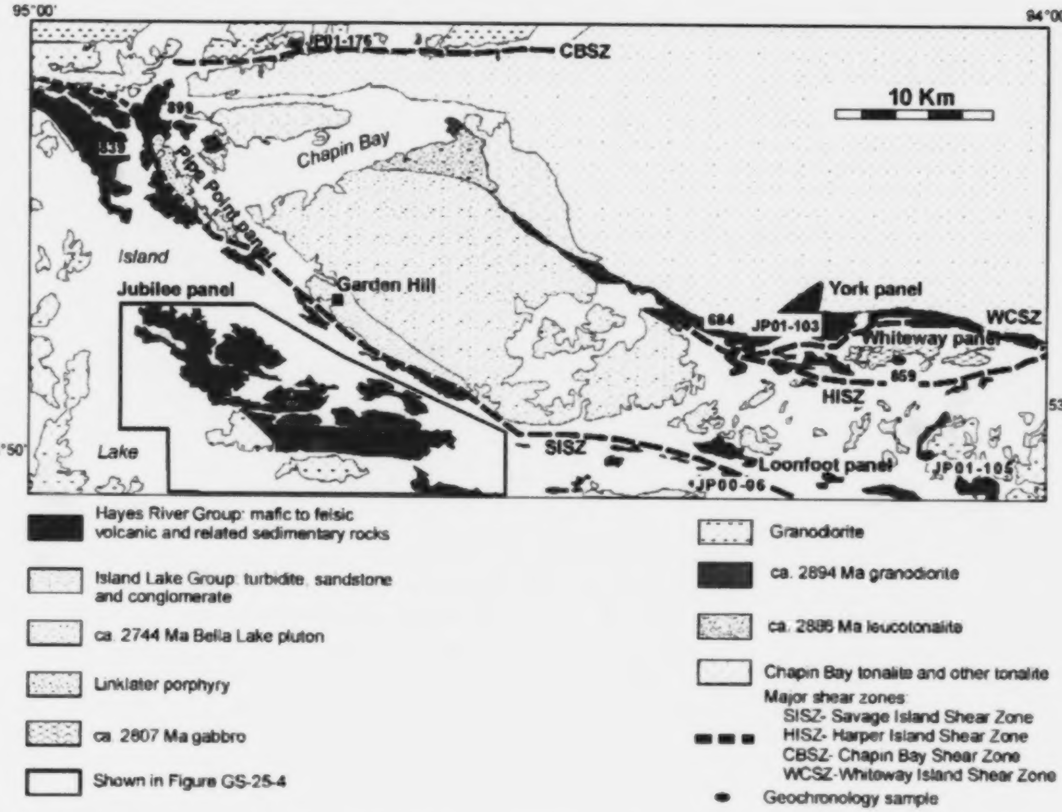

95°00'
94°00'
JP01-175
CBSZ
10 Km
899
839
Chapin Bay
Pipe Point panel
Island
Jubilee panel
Garden Hill
York panel
684
JP01-103
WCSZ
Whiteway panel
859
HISZ
53°50'
53°50'
Lake
SISZ
Loonfoot panel
JP01-105
JP00-06
Hayes River Group: mafic to felsic volcanic and related sedimentary rocks
Island Lake Group: turbidite, sandstone and conglomerate
ca. 2744 Ma Bella Lake pluton
Linklater porphyry
ca. 2807 Ma gabbro
Shown in Figure GS-25-4
Granodiorite
ca. 2894 Ma granodiorite
ca. 2886 Ma leucotonalite
Chapin Bay tonalite and other tonalite
Major shear zones:
SISZ- Savage Island Shear Zone
HISZ- Harper Island Shear Zone
CBSZ- Chapin Bay Shear Zone
WCSZ-Whiteway Island Shear Zone
Geochronology sample

Figure GS-25-1: Simplified geology of the Island Lake greenstone belt.

panels are here named the Jubilee panel (JP), Loonfoot panel (LP), Whiteway panel (WP), York panel (YP) and Pipe Point panel (PPP). It is clear that the use of the term 'Hayes River Group' needs to be re-evaluated for all of the volcanic rocks in this greenstone belt.

The Island Lake Group consists of sedimentary rocks including polymictic conglomerate, sandstone, and turbidite sequences; a detailed description is given in Lin et al. (1998) and Weber et al. (1982b). Based on detrital zircon work, this group has sampled material as old as ca. 3014 Ma (J. Parks, unpublished data, 2001). The age of sedimentation in the ILG is constrained to a maximum of ca. 2712 Ma, the youngest detrital zircon analyzed to date (Parks et al., 2001), and to a minimum of ca. 2699 Ma, the age of a crosscutting dike of the Horseshoe Island porphyry (Turek et al., 1986). Both the ILG and HRG are intruded by various plutons.

TECTONOSTRATIGRAPHY AND GEOCHEMISTRY IN THE HAYES RIVER GROUP (HRG)

Lin et al. (1998) first suggested that the HRG in the Island Lake greenstone belt could be divided into shear-zone–bounded panels that were possibly geochemically and chronologically distinct (Fig. GS-25-1). These shear zones are the Savage Island Shear Zone (SISZ), the Harper Island Shear Zone (HISZ) and the Whiteway Channel Shear Zone (WCSZ). Samples have been collected from all of the tectonostratigraphic panels for U-Pb geochronology, major- and trace-element geochemistry, and Nd isotopic analysis. Geochemical data presented here are preliminary and repeat analyses are planned, at research grade, to more accurately determine the trace-element composition of critical samples. Geochemical analyses have so far been used to help constrain and characterize the nature of the different panels but, with further analyses planned, a detailed petrogenetic study of the units will follow. Multi-element diagrams for each panel are presented here and have been normalized to the primitive mantle values of Sun and McDonough (1989).

Pipe Point panel (PPP)

The Pipe Point panel (central panel from Parks et al., 2001) is located in the northwestern portion of the map area and is north of the SISZ. This panel consists of mafic and felsic volcanic rocks and related gabbroic rocks. The basalt units in this panel are pillowed and aphyric. A deformed quartz porphyry has been dated at ca. 2730 Ma (sample 899 from Parks et al., 2001); however, its origin is controversial and it may be intrusive and therefore represent a minimum age for this panel. A felsic tuff with well-preserved volcanic features (e.g., volcanogenic clasts) was mapped this summer, and sampled for U-Pb geochronology to better constrain the age of this panel. The rocks in this panel are metamorphosed to greenschist facies, and are moderately to strongly deformed. Few locations preserve good candidates for geochemical sampling due to pervasive alteration and weathering along foliation planes in outcrop, and only two samples were taken this summer for geochemical analysis.

Jubilee panel (JP)

The Jubilee panel is located to the south of the SISZ, and is continuous across the entire map area (panel I from Parks et al., 2001; Fig. GS-25-1). This panel consists of mafic and felsic volcanic rocks, as well as associated volcanogenic sedimentary rocks and gabbroic intrusions. The stratigraphy and structure in this panel are discussed below. Two basaltic suites can be recognized, based on field mapping and preliminary geochemical data: one suite in the northern section of this panel and one in the south. Three felsic tuff units along the length of the panel have been dated, and all three samples yielded a U-Pb zircon age of ca. 2852 Ma (Corfu and Lin, 2000 and sample 839 from Parks et al., 2001).

The northern suite has a relatively flat profile on a multi-element diagram with a low total abundance of rare earth elements (REE), at 2 to 3 times primitive mantle (Fig. GS-25-2a). Spurious variations in La and Th will hopefully be improved with research-grade analyses. Note that, on this diagram, neither Nd nor Ta is present due to analytical uncertainties in their measurements. Basalt from the southern suite is enriched in Th and has a significant negative Nb anomaly (Fig. GS-25-2b). Lanthanum and cerium are relatively enriched compared to the middle REE, and the heavy rare earth elements (HREE) are slightly depleted.

Loonfoot panel (LP)

The Loonfoot panel is located in the eastern part of the map area, north of the SISZ and south of the HISZ (panel II from Parks et al., 2001; Fig. GS-25-1). This panel consists of mafic volcanic rocks, as well as rare occurrences of associated felsic volcanic rocks. Two basaltic suites can be recognized, based on field mapping and preliminary geochemical data: one suite in the northwestern section and the other in the eastern section of the panel (Lin et al., 1998; this study). The basalt in the northwestern suite is dark green to black, pillowed, has thin selvages, is aphyric and commonly contains epidote veining and sulphides. It is metamorphosed to greenschist facies. This suite is enriched in light rare earth elements (LREE) and Th, and slightly depleted in HREE (Fig. GS-25-2c). It also has a significant negative Nb anomaly. The eastern suite basalt is light green to grey, pillowed and massive, aphyric and commonly contains extensive quartz-carbonate veins. It is metamorphosed to greenschist facies. This suite has a flatter REE profile than rocks in the northwestern part of the panel and a lower abundance of these elements (Fig. GS-25-2d). Again the samples show a negative Nb anomaly and Th enrichment. An interlayered felsic tuff in the eastern part of the panel yielded a U-Pb zircon age of ca. 2744 Ma (sample JP01-105, J. Parks, unpublished data, 2002).

Whiteway panel (WP)

The Whiteway panel (panel III from Parks et al., 2001) is located in the eastern part of the map area (Fig. GS-25-1), and is north of the HISZ and south of the WCSZ. This panel consists of mafic volcanic rocks, gabbroic intrusions and rare lenses of volcanogenic sedimentary rocks. The basalt in this panel is pillowed, aphyric, has thin selvages and commonly exhibits sulphide alteration. A gabbroic intrusion in the basaltic package has a U-Pb zircon age of ca. 2807 Ma (Corfu and Lin, 2000), and five detrital zircons from a sedimentary lens have yielded essentially identical ages of ca. 2897 Ma (sample 859 from Parks et al., 2001). These ages bracket volcanism in this panel to a minimum of 2807 Ma, but possibly as old as 2897 Ma. This panel is metamorphosed to greenschist facies and is weakly to strongly deformed. This basaltic suite again shows strong enrichment in Th and LREE, and slight depletion in HREE (Fig. GS-25-2e). The rocks also have strong negative Nb and Ta anomalies and moderate negative Ti anomalies. This panel is geochemically similar and may correlate with the northwestern suite of the Loonfoot panel. This possibility is under further investigation.

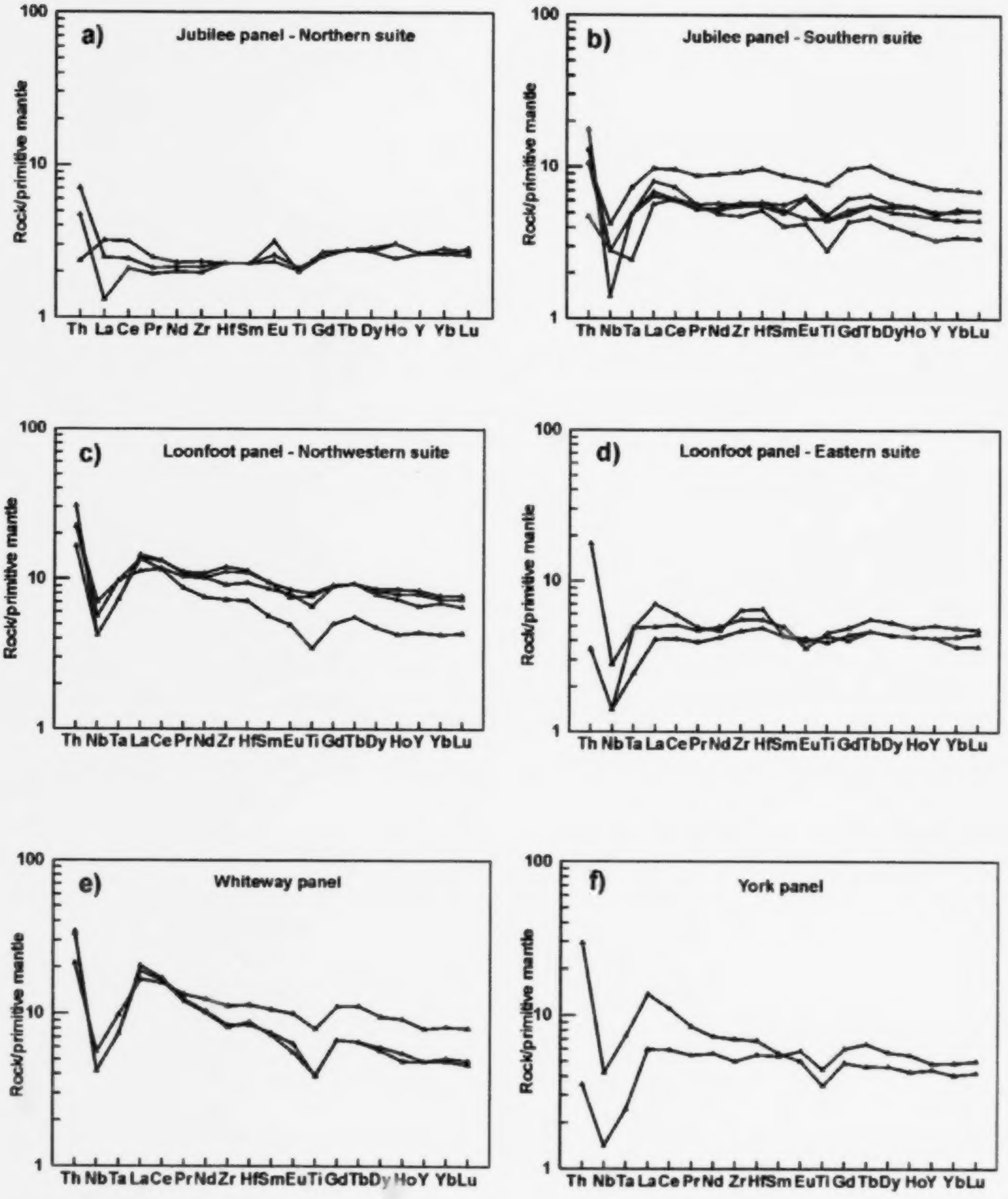


Figure GS-25-2: Multi-element plots of geochemical data. All values are normalized to the primitive mantle values of Sun and McDonough (1989). See text for discussion of data.

York panel (YP)

The York panel (panel IV from Parks et al., 2001) is located in the eastern part of the map area, and is north of the WCSZ (Fig. GS-25-1). Dominant rock types are mafic and ultramafic volcanic rocks. The basalt is most commonly pillowed, has thin selvages and is aphyric. A granodiorite that intrudes the basalt in this package has been collected for U-Pb dating to place a minimum age constraint on the age of this sequence. This panel is metamorphosed to amphibolite facies and is strongly deformed. Only two samples have been analyzed to date and they differ considerably in terms of LREE and Th characteristics (Fig. GS-25-2f). Both samples show relatively flat HREE profiles and negative Nb anomalies. The geochemistry of this unit is under further investigation to constrain the apparent range in variation.

STRUCTURE AND STRATIGRAPHY IN THE JUBILEE PANEL

The Island Lake greenstone belt has experienced multiple episodes of deformation. These deformation events have been responsible for folding much of the ca. 2852 Ma supracrustal rock sequence in the area and for producing four distinct shear zones found in this belt. The structure of these shear zones is discussed in Lin et al. (1998) and Parks et al. (2001). A major focus of the field program this summer was to investigate structure and stratigraphy in the oldest (2852 Ma) supracrustal package (Jubilee panel). To this end, detailed mapping was conducted that led to the recognition of major folds and elucidation of the stratigraphy of the volcanic rocks in this panel. Preliminary results are summarized below.

Stratigraphy

In the Jubilee Island area, primary features are locally well preserved and a continuous section of basalt (oldest), felsic volcanic and sedimentary rocks (youngest) is observed. The basalt (noted as northern suite above) is pillowed and massive, has thin selvages and is aphyric. Locally this basalt displays well-preserved primary structures, such as well-rounded pillows with cusps and flow-top breccia units that indicate tops are to the north (Fig. GS-25-3). A felsic volcanic unit overlies the basalt, and consists of tuffaceous beds and quartz-feldspar–phyric flows. Stratigraphically overlying this unit is a sedimentary unit that consists of a broad range of metasedimentary rocks, from argillite through sandstone to conglomerate. Primary features are well preserved, and features such as graded bedding indicate tops are also to the north. This sequence of units is repeated by folding in this area.

In the Confederation Island–Henderson Island area, a continuous section of basalt (oldest) to felsic volcanic rocks (youngest) is observed. The basalt unit (noted as southern suite above) is pillowed, aphyric and contains epidote as well as quartz-carbonate veining. Overlying the basalt is a felsic volcanic unit that is composed mainly of tuffaceous beds that have 1 to 2 mm rounded quartz and feldspar crystals set in a buff to grey, fine-grained felsic matrix. This unit is normally well foliated with pervasive chlorite alteration along planes of foliation. This package is also repeated by folding.

Separating these two stratigraphic packages is a shear-bounded package of rocks that includes basaltic and sedimentary units, as well as gabbroic intrusions.

Structure

Deformation in this area has produced tight to isoclinal folds. An axial-planar foliation strikes southeasterly to easterly and dips steeply south. Minor folds in sedimentary rocks are parasitic to the map-scale folds, and plunge both moderately to the west-northwest and shallowly to the east-southeast. Two macroscopic folds have been identified in the Jubilee panel: an anticline in the Jubilee Island area and a syncline in the Confederation Island–Henderson Island area (Fig. GS-25-4). These folds are defined by younging direction reversal, stratigraphic repetition of units and similar geochemical characteristics of the basalt in the limbs of the folds. Juxtaposed between these two fold structures is a shear-bounded package of basaltic and sedimentary rocks. This package is strongly deformed and sheared, both

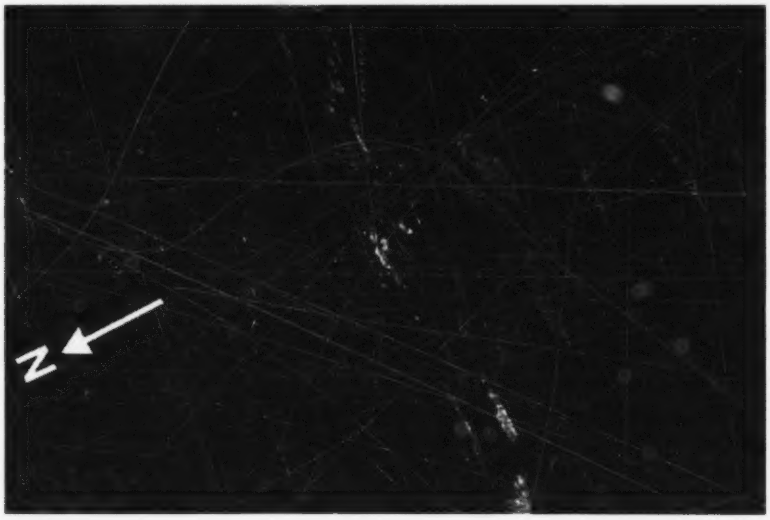


Figure GS-25-3: Well-preserved flow-top breccia and rounded pillows with cusp structures in the western part of the Jubilee panel. Tops are to the north.

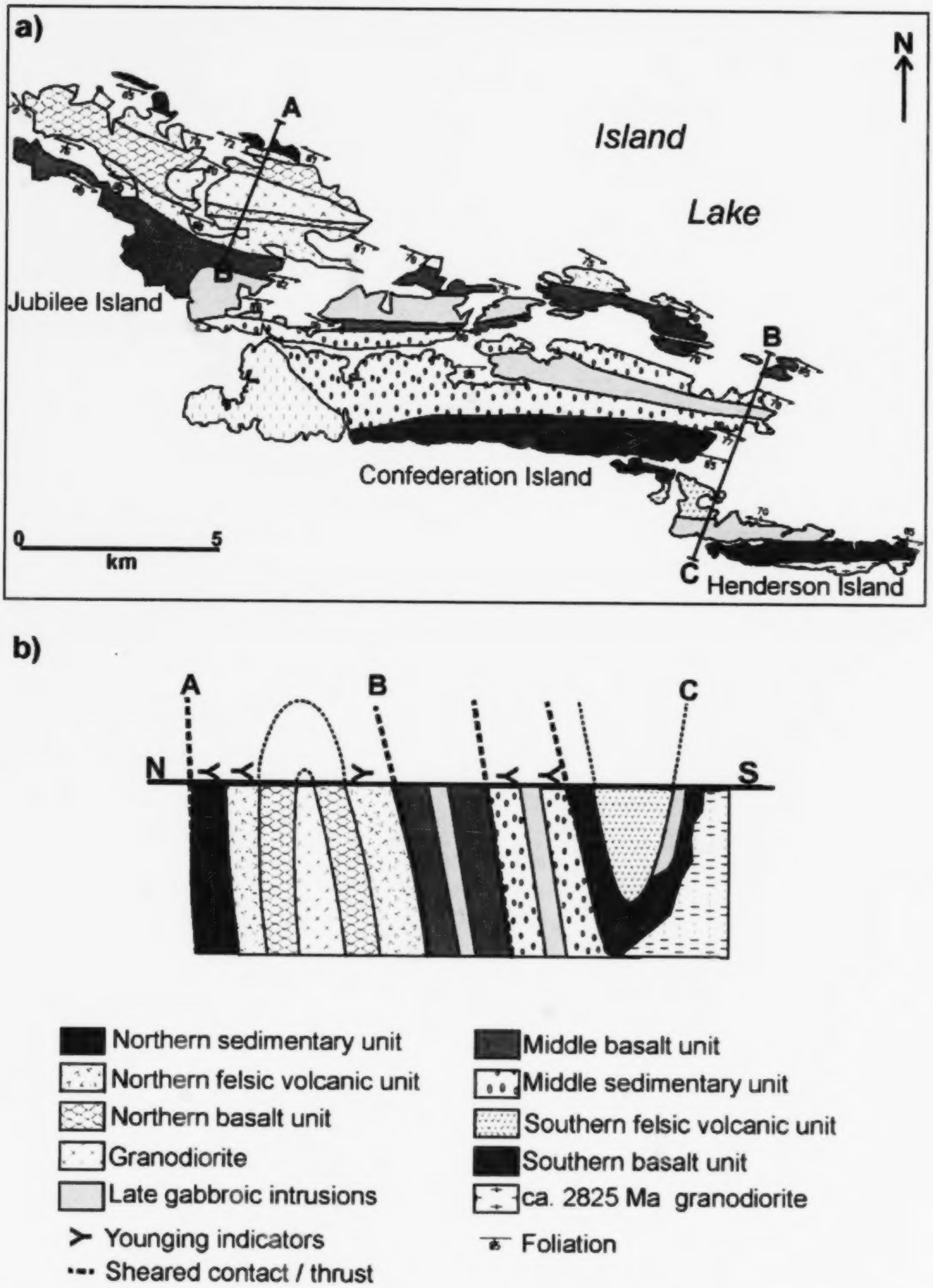

a)
N
Island
Lake
A
B
Jubilee Island
B
Confederation Island
0
5
km
C
Henderson Island
b)
A
B
C
N
S
Northern sedimentary unit
Northern felsic volcanic unit
Northern basalt unit
Granodiorite
Late gabbroic intrusions
Younging indicators
Sheared contact / thrust
Middle basalt unit
Middle sedimentary unit
Southern felsic volcanic unit
Southern basalt unit
ca. 2825 Ma granodiorite
Foliation

Figure GS-25-4: a) Detailed map of the Jubilee panel. b) Composite schematic cross-section of the geometry of the structure in this area; cross-section shows the interpreted anticline, syncline and thrust sheet; cross-section lines are shown in (a).

along its lithological contacts and internally (Fig. GS-25-5), and is interpreted to represent a thrust-sheet structure. In general, the degree of deformation in this panel varies from weak in the west to strong in the east. Primary features are well preserved in the west (Fig. GS-25-3), and are only rarely preserved as the limbs of the folds become more intensely deformed and sheared in the eastern part of the panel (Fig. GS-25-5).

TIMING OF DEFORMATION

A major objective of this project is to place geochronological constraints on the timing of deformation in this greenstone belt. In the Jubilee panel, a postkinematic quartz-porphyry dike yielded a preliminary zircon age of ca. 2724 Ma (sample JP00-06 from Parks et al., 2001). This dike cuts an early foliation that is subsequently seen to be transposed by the SISZ, and may place constraints on the early deformation event in this area (Fig. GS-25-6). An undeformed, post-tectonic granodiorite that intrudes the folded rocks in the Jubilee panel was collected this summer for U-Pb zircon analysis. The age of this granodiorite will also place a minimum age on the early deformation event. A sheared pretectonic tonalite in the CBSZ (sample JP02-176, this study) yielded a U-Pb zircon age of ca. 2747 Ma, and provides a maximum age for deformation along the CBSZ.

Two dikes have been dated in the HISZ. The first is a tonalite dike that is only weakly foliated and contains xenoliths of strongly foliated mafic rock (Fig. GS-25-7). This dike yielded a U-Pb zircon age of ca. 2722 Ma (sample 684 from Parks et al., 2001). The second dike is strongly internally foliated and folded within the country rock (Fig. GS-25-8). This dike yielded a zircon age of ca. 2701 Ma (sample JP01-103, J. Parks, unpublished data, 2002).

Figure GS-25-5: Deformed basalt in the eastern part of the Jubilee panel; deformation is strong in this area, with S- and Z-folds common at the outcrop scale.

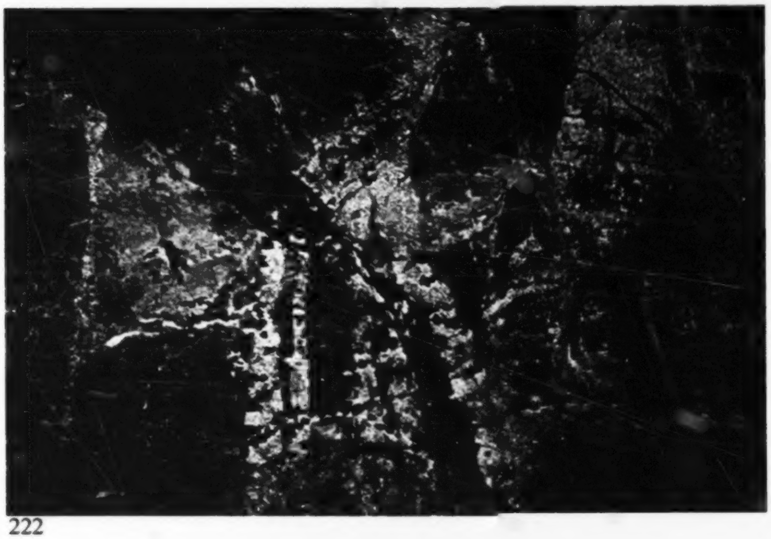


Figure GS-25-6: Coarse-grained porphyry dikes (running top to bottom in photo), cutting foliation in deformed mafic material (foliation running left to right in photo), sample JP00-06.

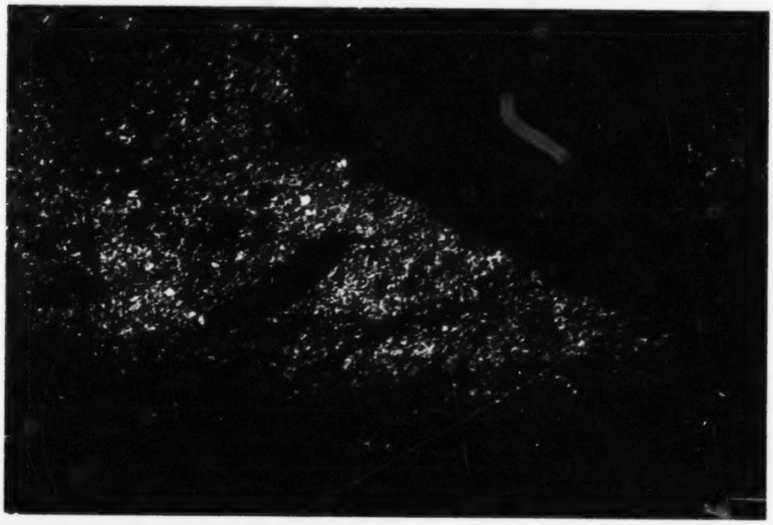


Figure GS-25-7: Weakly foliated tonalite dike containing xenoliths of foliated mafic material, sample 684.

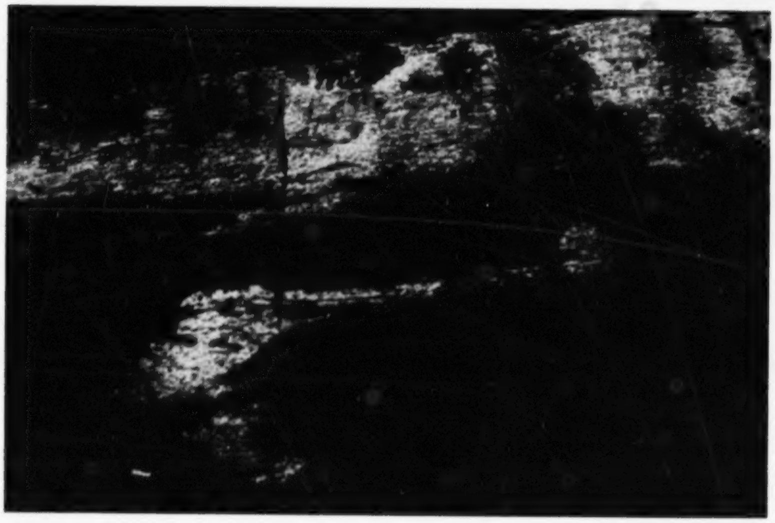


Figure GS-25-8: Strongly foliated dike folded within the country rock, sample JP01-103.

Three possibilities may explain why the older dike is less deformed than the younger one: 1) zircons analyzed from the older dike are inherited; 2) parts of the HISZ have been activated more than once; or 3) the older dike is more competent and did not experience as much deformation as the younger one did during movement along the HISZ.

NEODYMIUM ISOTOPE DATA

Stevenson and Turek (1992) completed a Nd isotopic investigation in the western part of the Island Lake greenstone belt. The ε_{Nd} values determined by Stevenson and Turek (1992) have been recalculated with the new U-Pb age date from this study (Fig. GS-25-9). Of particular interest is the range in positive to negative ε_{Nd} in this dataset, as well as a cluster of data points around a 3.0 Ga crustal ε_{Nd} evolution line. The older 2852 Ma volcanic package shows a range in positive to negative ε_{Nd} values, whereas the 2730 Ma volcanic rocks have entirely positive ε_{Nd} values. In contrast, a 2730 Ma tonalite and a suite of 2744 Ma tonalite and porphyry have entirely negative ε_{Nd} values. This range in data shows clearly that the rocks in this greenstone belt are strongly yet variably influenced by Mesoarchean crust of the ca. 3.0 Ga North Caribou Terrane. These data warrant further study to isotopically characterize the crust in this greenstone belt.

CONCLUSIONS AND FURTHER WORK

The Hayes River Group consists of lithologically, geochemically and chronologically distinct panels, and at least

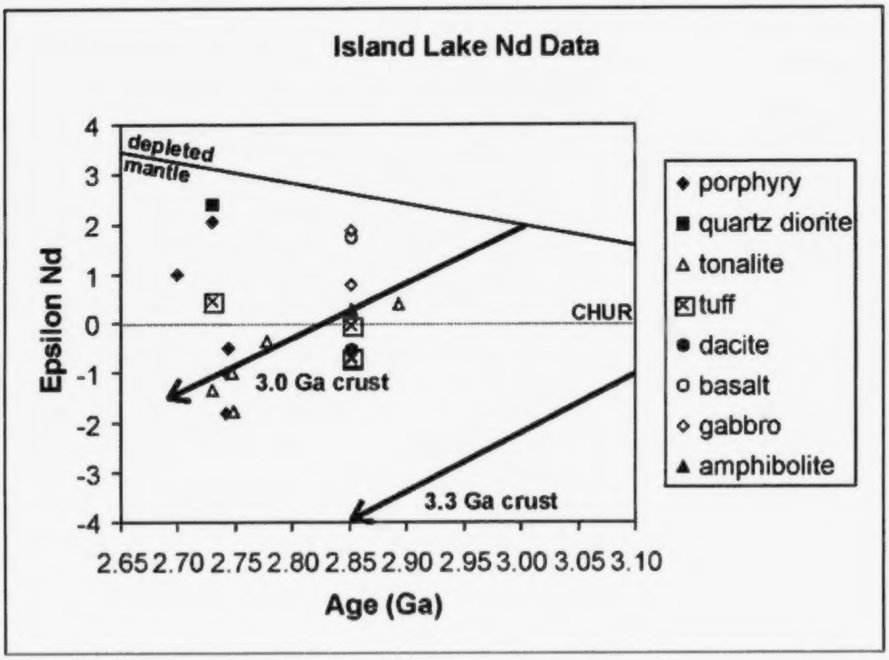


Figure GS-25-9: ε_{Nd} vs. age (Ga) plot, recalculated from data presented by Stevenson and Turek (1992); see text for discussion.

three volcanic episodes, at ca. 2852 Ma, ca. 2744 Ma and ca. 2730 Ma, are recorded as one group in this greenstone belt. New mapping this summer led to elucidation of the geometry of folding and recognition of a stratigraphy in the panel south of the Savage Island Shear Zone. The Nd isotopic characteristics of this greenstone belt are complex, and include both juvenile rocks and rocks influenced by Mesoarchean crust.

To further constrain the geological evolution of the Island Lake greenstone belt, additional U-Pb analyses will be done at the Jack Satterly Laboratory, Royal Ontario Museum (ROM). High-resolution geochemical analyses, including Sm-Nd work, are also planned to help characterize the different panels. In addition, variations in crustal contamination in the belt will be studied, using combined Nd isotopes and geochemistry, in the hope of identifying juvenile and contaminated units. These studies will help determine the significance of this greenstone belt in the context of its location on the margin of the North Caribou Terrane. Detailed microstructural work will be conducted on samples taken this summer. In particular, work will be done to test the geometry of the folds in the Jubilee Panel presented above, and the nature of the early deformation event.

ACKNOWLEDGMENTS

The Manitoba Geological Survey, the Northern Scientific Training Program, LITHOPROBE, NSERC and the University of Waterloo have generously supplied funding for this project. Geochronology analyses were done at the ROM's Jack Satterly Laboratory. We would like to thank Al Bailes for reviewing this manuscript, Ric Syme for the use of his samples and field notes, the staff at the ROM for their help, Scott Snider and Matt Chalaturnyk for their field assistance and Neill Brandson for logistical support.

REFERENCES

Corfu, F and Lin, S. 2000: Geology and U-Pb geochronology of the Island Lake greenstone belt, northwestern Superior Province, Manitoba; Canadian Journal of Earth Sciences, v. 37, p. 1275–1286.

Gilbert, H.P. 1984a: Loonfoot Island; Manitoba Energy and Mines, Preliminary Map 1984I-1, scale 1:20 000.

Gilbert, H.P. 1984b: Island Lake project; *in* Report of Activities 1984, Manitoba Energy and Mines, Mineral Resources, p. 120–125.

Gilbert, H.P. 1985a: Loonfoot Island; Manitoba Energy and Mines, Preliminary Map 1985I-3, scale 1:20 000.

Gilbert, H.P. 1985b: Island Lake; Manitoba Energy and Mines, Preliminary Map 1985I-3, scale 1:20 000.

Gilbert, H.P., Neale, K.L., Weber, W., Corkery, M.T. and McGregor, C.R. 1982: Island Lake; Manitoba Energy and Mines, Preliminary Map 1982I-4, scale 1:20 000.

Gilbert, H.P., Neale, K.L., Weber, W., Corkery, M.T. and McGregor, C.R. 1983: Island Lake; Manitoba Energy and Mines, Preliminary Map 1983I-1, scale 1:20 000.

Godard, J.D. 1963a: Island Lake; Manitoba Mines and Natural Resources, Mines Branch, Map 59-3A, scale 1: 63 360.

Godard, J.D. 1963b: Island Lake; Manitoba Mines and Natural Resources, Mines Branch, Map 59-3B, scale 1:63 360.

Lin, S. and Corfu, F. 2002: Structural setting and geochronology of auriferous quartz veins at the High Rock Island gold deposit, northwestern Superior Province, Manitoba, Canada; Economic Geology, v. 96, p. 43–57

Lin, S. and Cameron, H.D.M. 1997: Structural setting of the Au-bearing quartz veins at the Henderson Island gold deposit (Ministik mine), Island Lake, Manitoba; *in* Report of Activities 1997, Manitoba Energy and Mines, Geological Services, p. 6–12.

Lin, S., Cameron, H.D.M., Syme, E.C. and Corfu, F. 1998: Geological investigation in the Island Lake greenstone belt, northwestern Superior Province (parts of NTS 53E/15 and 16); *in* Report of Activities 1998, Manitoba Energy and Mines, Geological Services, p. 78–87.

McGregor, C.R. and Weber, W. 1982: St. Theresa Point; Manitoba Energy and Mines, Preliminary Map 1982I-3, scale 1: 20 000.

Neale, K.L. 1981: Island Lake–Sinclair–Savage Islands; Manitoba Energy and Mines, Preliminary Map 1981I-2, scale 1:20 000.

Neale, K.L. and Weber, W. 1981: Island Lake–Cochrane Bay; Manitoba Energy and Mines, Preliminary Map 1981I-1, scale 1:20 000.

Neale, K.L., Weber, W. and McGregor C.R. 1982: Garden Hill; Manitoba Energy and Mines, Preliminary Map 1982I-2, scale 1:20 000.

Parks, J., Lin, S., Corkery, M.T. and Davis, D.W. 2001: Geology and geochronology of the Island Lake greenstone belt, northwestern Superior Province; *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 115–120.

Skulski, T., Corkery, M.T., Stone, D., Whalen, J.B. and Stern, R.A. 2000: Geological and geochronological investigations in the Stull-Edmond lake greenstone belt and granitoid rocks of the northwestern Superior Province; *in* Report of Activities, 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 117–128.

Stevenson, R.K. and Turek, A. 1992: An isotope study of the Island Lake greenstone belt, Manitoba: crustal evolution and progressive cratonization in the late Archean; Canadian Journal of Earth Sciences, v. 29, p. 2200–2210.

Sun, S.S. and McDonough, W.F. 1989: Chemical and isotopic systematics of ocean basalts: implications for mantle composition and processes, *in* Magmatism in the Ocean Basins, A.D. Saunders and M.J. Norry (ed.), Geological Society, Special Publication No. 42, p. 313–345.

Theyer, P. 1998: Mineral deposits and occurrences in the Island Lake area, NTS 53E/15, 53E/16, 53F/13, 53E/10, 53E/9, 53E/12; Manitoba Energy and Mines, Mineral Deposits Report 32.

Thurston, P.C., Osmani, I.A. and Stone, D. 1991. Northwestern Superior Province: review and terrane analysis; *in* Geology of Ontario, P.C. Thurston, H.R. Williams, R.H. Sutcliffe and G.M. Stott (ed.), Ontario Geological Survey, Special Volume 4, Pt. 1, p. 81–142.

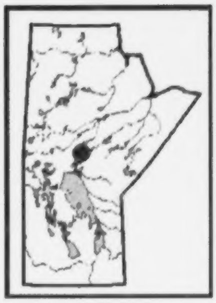
Turek, A., Carson, T.M., Smith, P.E., van Schmus, W.R. and Weber, W. 1986: U-Pb zircon ages from the Island Lake greenstone belt, Manitoba; Canadian Journal of Earth Sciences, v. 23, p. 92–101.

Weber, W., McGregor, C.R. and Neale, K.L. 1982a: Waasagomach Bay; Manitoba Energy and Mines, Preliminary Map 1982I-1, scale 1:20 000.

Weber, W., Gilbert, H.P., McGregor, C.R. and Neale, K.L. 1982b: Island Lake Project; *in* Report of Activities 1982, Manitoba Energy and Mines, Mineral Resources Division, p. 34–43.

GS-26 DEFORMATION HISTORY OF THE NORTHWESTERN CROSS LAKE GREENSTONE BELT (NTS 63I12), NORTHWESTERN SUPERIOR PROVINCE, MANITOBA

by T. Dai[1], D. Jiang[1] and M.T. Corkery



Dai, T., Jiang, D. and Corkery, M.T. 2002: Deformation history of the northwestern Cross Lake greenstone belt (NTS 63I12), northwestern Superior Province, Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 226–233.

SUMMARY

This paper reports on a structural study of a portion of the Cross Lake greenstone belt, northwest of the community of Cross Lake, as a continuation of an integrated mapping, geochronological, metamorphic and structural study of the central and southern parts of the belt (Dai et al., 2001). This year's field program revealed that

1) there were two generations of deformation in the Cross Lake Group prior to the deformation associated with the Central Cross Lake Shear Zone;
2) the contact between the main part (sandstone) of the Cross Lake Group and the underlying units is tectonic, likely a low-angle fault formed during the first generation of deformation and folded by the second generation of deformation;
3) the structural framework at the map scale is largely due to the second generation of deformation, which produced the northwest Cross Lake folds and the north Cross Lake anticlinorium in the northwestern Cross Lake area;
4) northeast-trending high-strain zones were produced during the second generation of deformation as a result of progressive strain localization; and
5) the central Cross Lake high-strain zone is the latest feature that overprints all structural elements in the area.

The recognition of this sequence of deformation may help explain the kinematic history of the Cross Lake greenstone belt.

INTRODUCTION

The Cross Lake greenstone belt, in the northwestern Superior Province in Manitoba, extends from the western end of the Gods Lake Domain westward into the Pikwitonei Granulite Domain. Two sets of high-strain zones stand out in the area, one trending east-southeast and the other trending northeast. They control the configuration of the supracrustal belt as well as the topographic pattern (Fig. GS-26-1). Previous studies in this area have focused on stratigraphy, geochronology and metamorphic history (Corkery, 1983, 1989; Corkery et al., 1988; Corkery and Lenton, 1989; Corkery et al., 1992). A thermotectonic pilot study of the Cross Lake greenstone belt was conducted by Breedveld (1989).

To unravel the tectonic history of the supracrustal belt, a structural study was initiated in the central Cross Lake area in the summer of 2001. In the first phase, a structural analysis of the Central Cross Lake Shear Zone (CCLSZ), a major east-southeast-trending shear zone (Fig. GS-26-1) near the southern margin of the greenstone belt, was carried out. The deformation history of that shear zone was outlined in Dai et al. (2001). Four generations of deformation were identified in the zone. The main fabric is a transposed foliation that is observed to cut all other recognized fabric elements of the Cross Lake greenstone belt, including the northeast-trending high-strain zones. Therefore, the main deformation of the CCLSZ is the latest event in the belt. What is the kinematic history prior to the CCLSZ deformation? How were pre-CCLSZ structures modified and overprinted by the CCLSZ? Answers to these questions are essential, not only to elucidate the tectonic history of the Cross Lake greenstone belt but also to understand the structures observed within the CCLSZ. During the past field season, structural analysis was conducted outside the CCLSZ, concentrating on the northwestern part of the greenstone belt where abundant clean shoreline exposures exist. The 2002 study area extends from the north shore of Cross Island about 6 km north and northwest to Eves Rapids (Fig. GS-26-1). This report is a preliminary synthesis of the structural framework of the Cross Lake greenstone belt.

LITHOLOGICAL UNITS

Supracrustal units

The Cross Lake greenstone belt consists of three groups of supracrustal rocks (Corkery et al., 1992):

---

[1] Department of Geology, University of Maryland, College Park, MD 20742, U.S.A.

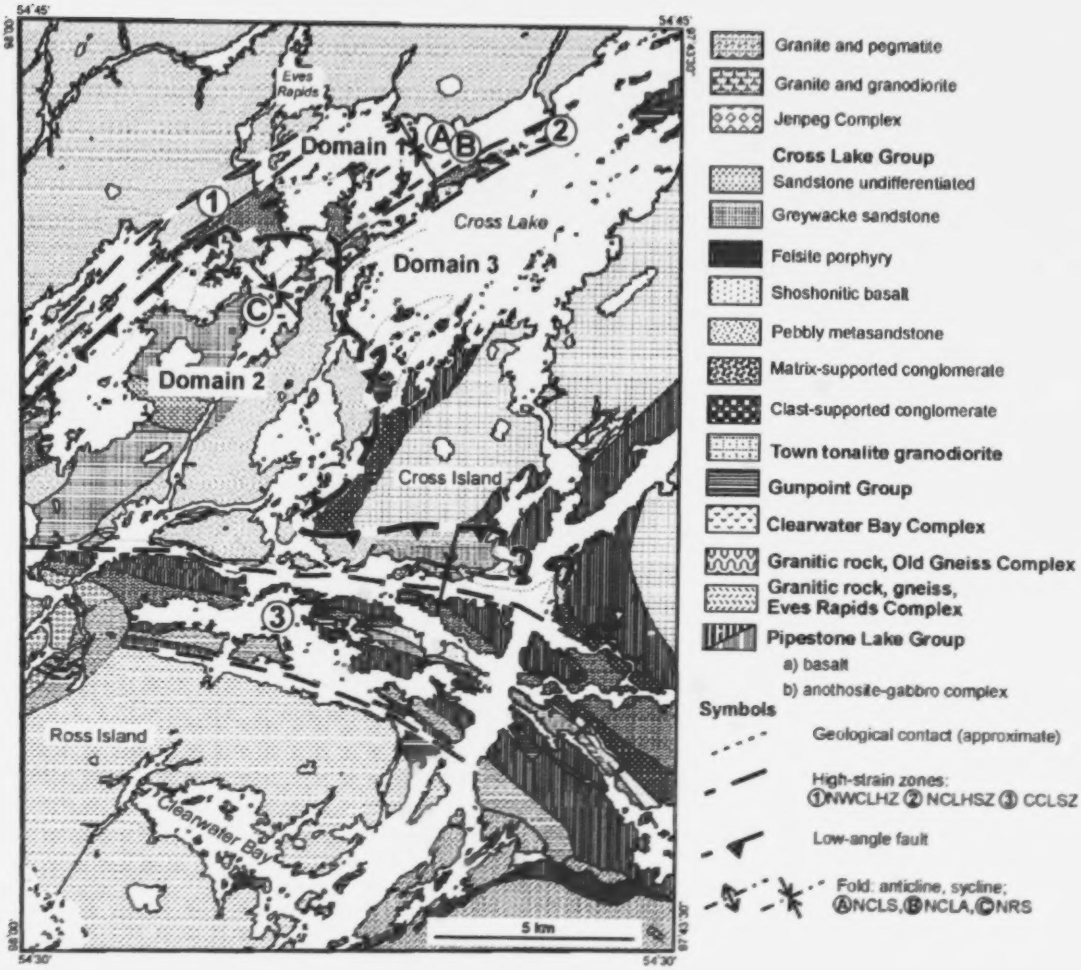

54°45'
98°00'
54°45'
97°43'30"
Eves Rapids
Domain 1
Domain 2
Domain 3
Cross Lake
Cross Island
Ross Island
Clearwater Bay
A
B
C
1
2
3
5 km
54°30'
98°00'
54°30'
97°43'30"
Granite and pegmatite
Granite and granodiorite
Jenpeg Complex
Cross Lake Group
Sandstone undifferentiated
Greywacke sandstone
Felsite porphyry
Shoshonitic basalt
Pebbly metasandstone
Matrix-supported conglomerate
Clast-supported conglomerate
Town tonalite granodiorite
Gunpoint Group
Clearwater Bay Complex
Granitic rock, Old Gneiss Complex
Granitic rock, gneiss, Eves Rapids Complex
Pipestone Lake Group
a) basalt
b) anothosite-gabbro complex
Symbols
Geological contact (approximate)
High-strain zones: ①NWCLHZ ② NCLHSZ ③ CCLSZ
Low-angle fault
Fold: anticline, sycline; Ⓐ NCLS, Ⓑ NCLA, Ⓒ NRS

Figure GS-26-1: Geological map of the northwestern Cross Lake area.

1) the Pipestone Lake Group (2760 Ma), a sequence of metavolcanic and subordinate metasedimentary rocks, consisting of weakly to strongly deformed pillowed and massive basalt flows, and related gabbro sills and dikes with minor iron formation;

2) the Gunpoint Group (2730 Ma), a fining-upward clastic sedimentary sequence with interbedded felsic volcanic rocks; and

3) the Cross Lake Group (<2710 Ma), a sequence of fluvial-marine clastic sedimentary rocks with shoshonitic volcanic rocks near the top.

Although the contacts between these three groups are interpreted to be unconformable, they are all tectonic in places where the contacts are observed in the study area. The metamorphic grade of the Cross Lake greenstone belt increases from upper greenschist facies in the Pipestone Lake area to hypersthene granulite grade in the gneissic terrane northwest of Cross Lake (Breedveld, 1989).

Intrusive rocks

Early intrusive rocks within the greenstone belt are either contemporaneous with or postdate the Pipestone Lake Group, but predate the Cross Lake Group. The Pipestone Lake anorthosite complex (2760 Ma), a north-facing layered intrusion dominated by megacrystic anorthosite and melagabbro that is interpreted to be contemporaneous with the Pipestone Lake Group (Corkery et al., 1992), pinches out to the east along a sheared contact in the southeast corner of

Pipestone Lake, and to the west along the southeast shore of Whiskey Jack bay[2] (Parmenter, 2002). The Eves Rapids Complex, which consists of hornblende and biotite tonalite and granodiorite, forms the northern boundary of the greenstone belt along the north shore of Cross Lake. The Whiskey Jack Complex (2734 Ma), dominated by medium- to coarse-grained orthogneiss, intrudes the Pipestone Lake Group along the southeast side of Whiskey Jack bay and is interpreted to be the northern margin of the Molson Lake Domain (Lenton et. al., 1986). The Town tonalite intrusion (2719 Ma), around which the supracrustal belt bifurcates in central Cross Lake, is unconformably overlain by conglomerate of the Cross Lake Group northwest of the town of Cross Lake.

Late intrusive rocks, which postdate all of the supracrustal rocks, include the Clearwater Bay Batholith (2691 Ma), a biotite granodiorite southwest of Whiskey Jack bay, and the Playgreen Complex granite and megacrystic granite, in the southwest near Jenpeg. Both of these intrude Cross Lake Group conglomerate on the south side of the supracrustal belt. A series of simple pegmatite dikes intrudes the Cross Lake Group sandstone at the west end of the belt (Corkery et al., 1992). As well, two series of rare element–enriched (2656 Ma) pegmatites are the latest intrusive rocks recognized in the area.

STRUCTURAL ANALYSIS

The map area is divided into three structural domains (Fig. GS-26-1). Domain I is bounded to the north by the Eves Rapids Complex. Its northwest and southeast boundaries are, respectively, the northwest Cross Lake high-strain zone (NWCLHZ) and the north Cross Lake high-strain zone (NCLHSZ), both trending approximately 040°. The southern limit of domain I is the contact between the Cross Lake Group conglomerate and sandstone. The northern boundary of the CCLSZ and the contact between the Cross Lake Group sandstone and underlying units enclose domain II. Domain III is on the east side of the NCLHSZ, and extends eastwards to the Town tonalite. The contact between the Gunpoint Group conglomerate and the overlying Cross Lake Group forms the west and south boundaries of domain III. Two generations of deformation were identified during this year's mapping in the Cross Lake Group supracrustal rocks in domains I and II. The structure of domain III is an anticlinorium, detailed fieldwork on which will be completed next year.

Deformation D_1

Foliations

Bedding (S_0) is generally recognizable on most outcrops outside of the northeast-trending high-strain zones. Primary structures such as crossbedding and graded bedding are preserved in the Cross Lake Group conglomerate and sandstone (Fig. GS-26-2). They both serve as markers and indicators of the younging direction where they are not strongly deformed.

There is a cleavage (S_1) axial planar to F_1 folds, defined by a preferred alignment of hornblende and biotite in the supracrustal rocks, and flattened clasts and pebbles. This cleavage is usually subparallel to S_0, but may be inclined close to the hinge areas of F_1 folds (Fig. GS-26-3). This relationship is best preserved in the crossbedded conglomerate and pebbly sandstone (Fig. GS-26-2). The S_0-S_1 geometry relationship indicates the overall Z-asymmetry of F_1 folds.

Bedding is generally transposed, due to isoclinal folding and boudinage (Fig. GS-26-4), to form a composite foliation S_T, which dips steeply to subvertically. Where the transposition is significant, S_0 and S_1 cannot be distinguished.

Lineations

There are three types of L_1 lineation, defined by 1) preferred alignment of hornblende and biotite minerals

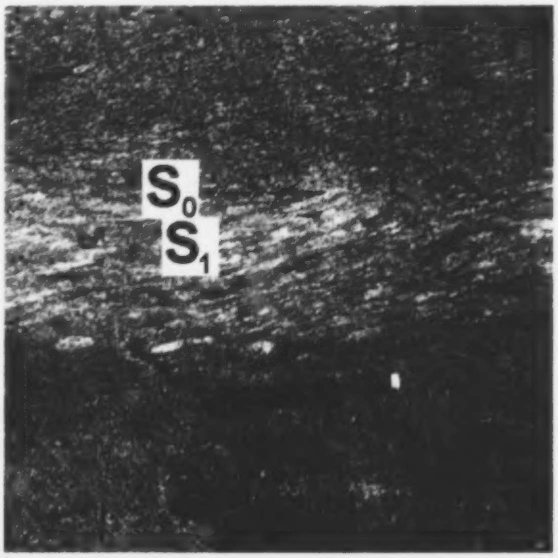


Figure GS-26-2: S_0-S_1 relationship in Cross Lake Group crossbedded pebbly sandstone, northern Cross Island. Pencil oriented towards 060°.

---

[2] unofficial name

Figure GS-26-3: L_1 lineation defined by vertically stretched clasts (looking south), northern Cross Lake.

on S_0 and S_1 (Fig. GS-26-5a); 2) stretched clasts and pebbles (Fig. GS-26-5b); and 3) the intersection of S_1 and S_0 with the F_1 fold axes. In domains I and III, all three types are parallel to each other, and plunge steeply to subvertically (Fig. GS-26-5a, c). In domain II, lineations defined by F_1 fold axes show significant variation (from subhorizontal to subvertical), but they define a common great circle parallel to the attitude of the northeast-trending high-strain zones (Fig. GS-26-5b), suggesting that fold axes have been rotated significantly (*see* discussion below).

Folds

Tight to isoclinal folds are often observed on outcrops, and can have S- or Z-asymmetry. Sheath folds are observed in some places (Fig. GS-26-6). The axes of F_1 folds were only measured in domain II. In that area, F_1 fold axes plunge variably, suggesting strong rotation of F_1 folds (Fig. GS-26-5b) by a later deformation.

No map-scale F_1 folds were recognized. The repetition of stratigraphy in the Cross Lake Group conglomerate at the northeast tip of domain I is interpreted as an F_1 fold closure (Fig. GS-26-1). However, since it is within the NCLHSZ and the facing of the conglomerate beds could not be determined, this interpretation could not be confirmed. If this interpretation is correct, then the map-scale structure of domain I is an F_1 fold refolded by F_2 (*see* 'Deformation D_2' section, below).

Figure GS-26-4: Boudinaged calc-silicate layer in the Cross Lake sandstone, overprinted by an F_2 fold (looking southeast), northwestern Cross Lake.

Boudinage

Boudin structures were observed, at scales varying from centimetres to metres, in pegmatite and amphibolite layers. The separation of boudins can sometimes be greater than their long dimension, as seen on outcrop, but the layer from which a chain of boudins was derived can usually be recognized. The boudinage is a D_1 structure, and is evidently overprinted by later deformation: the boudinaged layers are commonly shortened and folded, as shown in Figure GS-26-4.

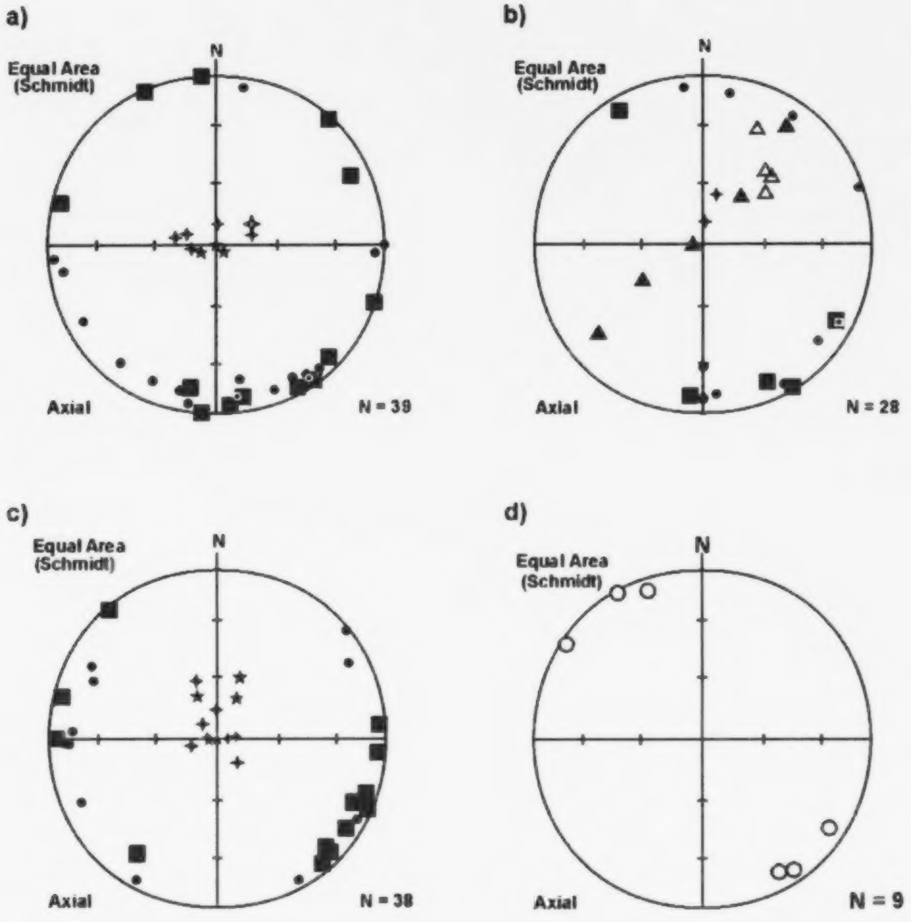


Figure GS-26-5: Equal area lower hemisphere plot of bedding S_0 (dot), S_1 (square), S_2 (circle), L_1 (triangle), F_1 (solid triangle), L_2 (star) and F_2 (cross) for: a) domain I, b) domain II, c) domain III, and d) north Cross Lake high-strain zone (NCLHSZ). Note the similarity of structures in domains I and III, and their contrast with those of domain II (see text for detail).

Figure GS-26-6: F_1 sheath fold in Cross Lake Group sandstone, northern Cross Lake.

Deformation D_2

The D_2 deformation overprints S_0, S_1 and S_T, and produces macroscopic F_2 folds in addition to small-scale F_2 folds observable on outcrops. The map-scale structural framework of the north Cross Lake greenstone belt is largely due to D_2 deformation.

Foliations and lineations

The S_2 foliation occurs as a crenulation cleavage overprinting S_T throughout the map area. In the long limb of F_2 folds, it appears as extensional 'shear bands' (Fig. GS-26-7), whereas it occurs as 'kink bands' in the short limbs. The S_2 foliation strikes approximately northeast and dips subvertically.

The L_2 lineation is recognizable if it occurs on S_2 as a mineral lineation. This lineation is also defined by F_2 fold axes. Lineations by stretched clasts are difficult to distinguish from L_1, since L_1 and L_2 are sometimes parallel due to the overprinting of D_2 deformation. The L_2 lineation plunges steeply to subvertically (Fig. GS-26-3).

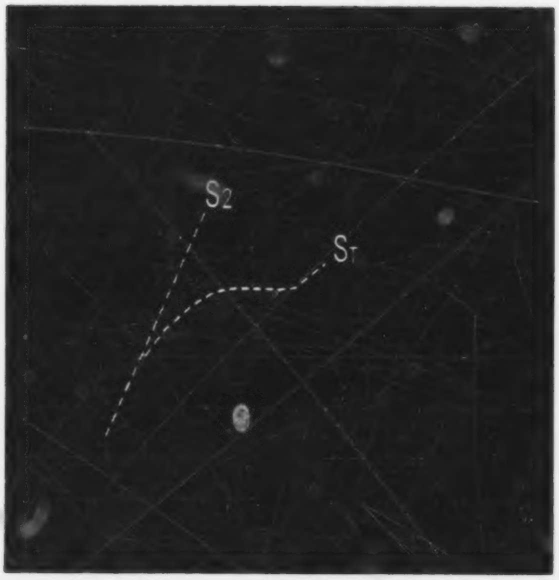


Figure GS-26-7: Crenulation cleavage in Cross Lake Group conglomerate (looking south), northern Cross Lake.

Folds

At outcrop scale, F_2 folds are open to tight asymmetric Z- and S-folds. The macroscopic F_2 folds are recognized based on the overprinting relationship between S_2 and S_T, and the consistent younging direction of Cross Lake Group rocks in open F_2 folds. Macroscopic F_2 folds include a syncline and anticline in domain I, and a syncline in domain II. In domain I, the syncline and anticline are referred to as the northwest Cross Lake syncline (NCLS) and the northwest Cross Lake anticline (NCLA; Fig. GS-26-1). The NCLS plunges steeply towards the northeast, and is defined by the Cross Lake Group clast-supported conglomerate and overlying matrix-supported conglomerate. Bedding is north facing on the north limb and east facing near the hinge. The NCLA is a tight, northeast-plunging anticline. If the interpretation of an F_1 fold closure in the long limb of the NCLA is correct, the Cross Lake Group on the southeast side of the NCLHSZ should all be facing southeast, and there should exist macroscopic, southeast-facing F_2 folds beneath domain II. Unfortunately it was not possible to confirm this interpretation because the high strain in the NCLHSZ has obscured the facing of the rocks. Both the NCLS and NCLA form a map-scale F_2 Z-fold. The syncline in domain II is referred to as the Nelson River syncline (NRS). It plunges towards northeast, and is defined by the contact between trough-crossbedded pebbly sandstone and thinly bedded sandstone and siltstone of the Cross Lake Group (Fig. GS-26-1). The facing of the limbs is hard to identify due to significant transposition by later, high-strain deformation.

The structure in domain III is an anticlinorium, the core of which consists of the Gunpoint and Pipestone Lake groups (Fig. GS-26-5c). Mafic flows of the Pipestone Lake Group outcrop as a structural window within the anticlinorium. Since detailed fieldwork has not yet been carried out in domain III, next summer's fieldwork will be concentrated here.

Northeast-trending high-strain zone deformation

The northeast-trending high strains result from progressive strain localization of D_2 deformation. This is based on the observation that structures in the high-strain zones show similar geometric and kinematic characteristics to those outside the high-strain zones, except that the intensity of deformation is much stronger in the high-strain zones. In the NCLHSZ, bedding cannot be identified at the outcrop scale due strong transposition. The dominant fabric of the NCLHSZ is an S_2 foliation, which is a composite foliation parallel to the high-strain zone. This foliation dips steeply to subvertically towards northeast (Fig. GS-26-5d).

DISCUSSION

Contact between the Cross Lake Group sandstone and underlying units

In the map area, the Cross Lake Group sandstone is the most widespread and continuous unit. It is in angular contact with the Cross Lake Group conglomerate (the boundary between domains I and II); in angular and direct contact with the north Cross Lake anticlinorium in domain III, where the Cross Lake Group conglomerate is missing; and in contact with Cross Lake Group conglomerate on southern Cross Island. Corkery et al. (1992) interpreted the Cross Lake clast-supported conglomerate to be the basal conglomerate marking the angular unconformity between the entire Cross Lake Group and the underlying units. The authors do not dispute this interpretation, but note that the distribution of conglomerate is isolated and discontinuous, in strong contrast to that of the sandstone. If this feature is primary, then the initial contact between the sandstone and the underlying units must represent a transgressive unconformity. An alternative interpretation is that the contact was a low-angle fault (thrust or detachment fault) formed during D_1 deformation. Regardless of the initial nature of the contact, it now marks a major structural boundary across which the style of post-D_1 deformation varies considerably. Below the contact in domains I and III, structural geometries are similar: S_0 and S_1 dip subvertically everywhere, L_1 and L_2 lineations are parallel and subvertical, and F_2 folds plunge steeply to subvertically (Fig. GS-26-5a, c). Above the contact in domain II, F_1 folds plunge variably from subhorizontally to subvertically, whereas F_2 folds plunge steeply to subvertically (Fig. GS-26-5b). Below the contact, in the domain III anticlinorium, the Pipestone Lake Group outcrops as a tectonic window (Fig. GS-26-1).

Kinematics and deformation history of the Cross Lake Group supracrustal rocks

Based on the observations outlined above, the authors conclude that D_1 is a major crustal shortening event that resulted in isoclinal folding and transposition of S_0 in the Cross Lake Group and possibly the development of a low-angle thrust fault. Although it is difficult to infer the kinematics of D_1 due to later overprinting, it is possible that the D_1 and D_2 deformations represent continuous progressive deformation. The D_2 deformation is a pure-shear–dominated (northwest-southeast shortening) transpression. The overall Z-asymmetry of F_2 folds suggests that there is a dextral transcurrent component. Strong vertical stretch during D_2 as a result of the pure shear component of transpression leads to the rotation of all L_1 lineations to the vertical orientation. Therefore, all L_1 lineations except some F_1 fold axes in domain II are also stretching lineations. The contact between Cross Lake sandstone and the underlying units serves as a mechanical boundary (like a décollement) during D_2 deformation. Above the contact, the rotation of F_1 fold axes is less significant than that below the contact. It is the D_2 deformation that contributes to the overall structural framework of the north Cross Lake greenstone belt. Progressive strain localization of D_2 deformation leads to the formation of the northeast-trending high-strain zones. All the deformation structures described above are cut by the CCLSZ (Dai et al., 2001). Thus, the work of the past two field seasons has documented the deformation sequence since the deposition of the Cross Lake Group. Deformation of the Cross Lake greenstone belt prior to this will constitute the focus of next year's work.

The fieldwork carried out in 2002 helps to explain the pre-CCLSZ deformation of the Cross Lake greenstone belt, which was not well studied last year. The F_1 isoclinal folds in the CCLSZ, which were described in Dai et al. (2001), are possibly inherited here from the F_1 and F_2 described above. The hypothesis of the low-angle thrust fault may give some indication of possible early horizontal movement in the Archean Cross Lake greenstone belt.

ACKNOWLEDGMENTS

The project is supported by the University of Maryland and by Manitoba Industry, Trade and Mines. The authors would like to express their gratitude to Neill Brandson for his support and to Patrick Norman and Jennifer Greville for their tireless field assistance.

REFERENCES

Breedveld, M. 1989: A thermo-tectonic pilot study of the Cross Lake gneiss-greenstone terrane, Superior Province, Manitoba, Canada; Free University, Amsterdam, Institute of Earth Sciences, internal report.

Corkery, M.T. 1983: Cross Lake supracrustal investigation; *in* Report of Activities 1983, Manitoba Department of Energy and Mines, Mineral Resources Division, p. 32–45.

Corkery, M.T. 1989: Cross Lake supracrustal geological investigation; *in* Report of Activities 1989, Manitoba Energy and Mines, Minerals Division, p. 88–90.

Corkery, M.T. and Lenton, P.G. 1989: Cross Lake supracrustal geological investigations; *in* Report of Field Activities 1989, Manitoba Energy and Mines, Minerals Division, p. 88–90.

Corkery, M.T., Breedveld, M. and Davis D.W. 1988: Cross Lake geological investigation; *in* Report of Activities 1988, Manitoba Energy and Mines, Minerals Division, p. 106–110.

Corkery, M.T., Davis, D.W. and Lenton, P.G. 1992: Geochronological constraints on the development of the Cross Lake greenstone belt, northwest Superior Province, Manitoba; Canadian Journal of Earth Sciences, v. 29, p. 2171–2185.

Dai, T., Jiang, D. and Corkery, M.T. 2001: Deformation history of the central Cross Lake greenstone belt, northwestern Superior Province, Manitoba; *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 111–114.

Lenton, P.G., Corkery, M.T. and Cameron, H.D.M. 1986: Kiskittogisu-Playgreen lakes area; *in* Report of Activities 1986, Manitoba Energy and Mines, Minerals Division, p. 150–151.

Parmenter, A. 2002: The structural evolution of the Pipestone Lake area in the Cross Lake greenstone belt, northwestern Superior Province, Manitoba; M.Sc. thesis, University of Waterloo, Waterloo, Ontario.

GS-27 PRELIMINARY REPORT ON THE GEOLOGY AND STRUCTURE OF THE GARNER LAKE AREA, SOUTHEAST RICE LAKE GREENSTONE BELT (NTS 52L14), MANITOBA

by S.D. Anderson

Anderson, S.D. 2002: Preliminary report on the geology and structure of the Garner Lake area, southeast Rice Lake greenstone belt (NTS 52L14), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 234–249.

SUMMARY

The Rice Lake greenstone belt, located in the western portion of the Archean Uchi Subprovince, is the most significant lode-gold district in Manitoba, with more than 1.7 million ounces of past gold production. In 2002, the Manitoba Geological Survey initiated a multidisciplinary program of targeted 1:20 000-scale bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology in the Rice Lake belt. The objective of this program is to further refine the stratigraphic, structural and tectonic framework of the belt, with particular emphasis on gold metallogeny. Fieldwork in 2002 focused on detailed mapping and sampling of a roughly 12 km transect across the southeast portion of the Rice Lake belt, utilizing exposures along the Gem Lake logging road and the shoreline of Garner Lake.

Four distinct tectonostratigraphic domains have been identified across the transect, each of which is bounded by major ductile shear zones that trend north or northwest. One of these domains includes the 'Garner narrows[1] assemblage', herein proposed for the north-facing sequence of arkosic wacke, andesitic volcanic rocks, iron formation and komatiitic flows that is exposed through the narrows in Garner Lake. This assemblage, the age of which is currently being investigated by U-Pb zircon geochronology, is similar to Mesoarchean (ca. 2.99 Ga) rift sequences elsewhere in the Uchi Subprovince.

In contrast to previous interpretations, overprinting relationships clearly indicate that the major domain-bounding shear zones postdate the regional D_2 deformation; however, the implications of this distinction for gold exploration remain unclear. To this end, a major focus of future work will be to document the stratigraphic and structural setting of gold occurrences in the Garner Lake area in the context of the framework outlined in this report. This information will provide insight into the mineralization process and controls, and constrain predictive models for gold in the southeast Rice Lake belt.

INTRODUCTION

The Rice Lake greenstone belt is the most significant lode-gold district in Manitoba, with hundreds of documented gold occurrences (e.g., Stockwell, 1940; Theyer and Yamada, 1989; Theyer and Ferreira, 1990; Theyer, 1991, 1994a, b; Richardson and Ostry, 1996) and historic production of approximately 1.73 million ounces of gold from several past-producing mines, including 1.42 million ounces from the San Antonio mine at Bissett (Whiting and Sinclair, 1990). Studies conducted under the auspices of the Canada-Manitoba Partnership Agreement on Mineral Development and the Western Superior NATMAP project have provided important new insights into the complex stratigraphic, structural and metallogenic evolution of the Rice Lake belt. Recent bedrock mapping, U-Pb geochronology and geochemistry have established, for example, the local presence of Mesoarchean (ca. 2.9 Ga) quartzite–iron formation–komatiite rift sequences, in addition to the more extensive Neoarchean (ca. 2.73 Ga) volcanic-arc successions (Fig. GS-27-1; e.g., Poulsen et al., 1996; Sasseville and Tomlinson, 1999, 2000; Percival et al., 2001, 2002). In this regard, it is now apparent that the tectonostratigraphy of the Rice Lake belt is analogous to that in the adjacent Red Lake greenstone belt in northwestern Ontario (e.g., Poulsen et al., 1996; Sanborn-Barrie et al., 2000, 2001).

Aside from contributing significantly to the understanding of the Rice Lake belt, these studies have also revealed challenging problems and directions for further research. For example, despite the correlative tectonostratigraphy in the Red Lake and Rice Lake belts, the vast majority of gold production (>20 million ounces) in the former has been derived from Mesoarchean hostrocks; in contrast, gold production in the latter came mainly from Neoarchean rocks. Moreover, although the importance of structural controls on the distribution of gold mineralization in the Rice Lake belt has been clearly demonstrated (e.g., Stockwell, 1940; Stephenson, 1972; Lau, 1988; Brommecker et al., 1989; Brommecker, 1991; Poulsen et al., 1996), the structural geology and deformation history of large areas of the belt remain poorly understood.

---

[1] unofficial place name

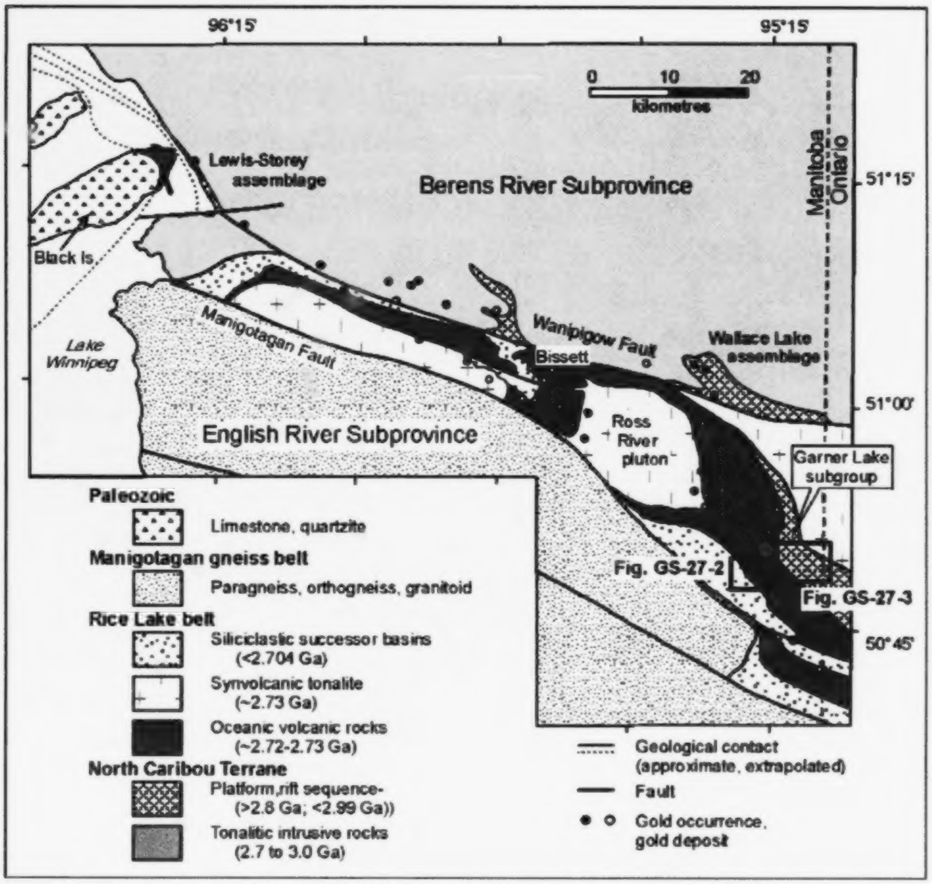

96°15'
95°15'
0
10
20
kilometres
Manitoba
Ontario
51°15'
51°00'
50°45'
Lewis-Storey assemblage
Berens River Subprovince
Black Is.
Lake Winnipeg
Manigotagan Fault
Wanipigow Fault
Bissett
Wallace Lake assemblage
English River Subprovince
Ross River pluton
Garner Lake subgroup
Fig. GS-27-2
Fig. GS-27-3
Paleozoic
Limestone, quartzite
Manigotagan gneiss belt
Paragneiss, orthogneiss, granitoid
Rice Lake belt
Siliciclastic successor basins (<2.704 Ga)
Synvolcanic tonalite (~2.73 Ga)
Oceanic volcanic rocks (~2.72-2.73 Ga)
North Caribou Terrane
Platform,rift sequence- (>2.8 Ga; <2.99 Ga))
Tonalitic intrusive rocks (2.7 to 3.0 Ga)
Geological contact (approximate, extrapolated)
Fault
Gold occurrence, gold deposit

Figure GS-27-1: Simplified geology of the Rice Lake belt (after Richardson and Ostry, 1996). The locations of Figures GS-27-2 and GS-27-3 are indicated.

In order to address these and other outstanding problems, the Manitoba Geological Survey (MGS) has initiated a multiyear, multidisciplinary project with the objective of further refining the stratigraphic, structural and tectonic framework of the Rice Lake belt, with particular emphasis on gold metallogeny and the recently documented Mesoarchean rift sequence. This collaborative project will mainly involve targeted 1:20 000-scale bedrock mapping, structural analysis and lithogeochemistry (S. Anderson, C. Beaumont-Smith and T. Corkery, MGS), in conjunction with the focused application of U-Pb geochronology (C. Böhm; University of Alberta).

In the summer of 2002, fieldwork focused on detailed mapping and sampling of a roughly 12 km transect across the southeast portion of the Rice Lake belt, utilizing exposures along the Gem Lake logging road and the shoreline of Garner Lake (Fig. GS-27-1, GS-27-2, GS-27-3). Due to the combination of complex stratigraphy and structure, a lack of comprehensive mapping coverage and the evidence for a thick package of komatiitic volcanic rocks (Brommecker et al., 1993), the Garner Lake area has been considered key to unravelling the complex geological history of the Rice Lake belt (e.g., Poulsen et al., 1994; Corkery, 1995, 1999). This mapping, the preliminary results of which are summarized below, will be complemented by U-Pb geochronology and lithogeochemistry to provide an updated geological framework for ongoing investigations in the southeast Rice Lake belt.

REGIONAL SETTING

The Archean Rice Lake greenstone belt is located in the westernmost exposed portion of the volcanoplutonic Uchi Subprovince of the Superior Province. In Manitoba, the Uchi Subprovince is flanked to the north by the North Caribou Terrane (Berens River Subprovince) and to the south by the Manigotagan gneiss belt of the English River Subprovince

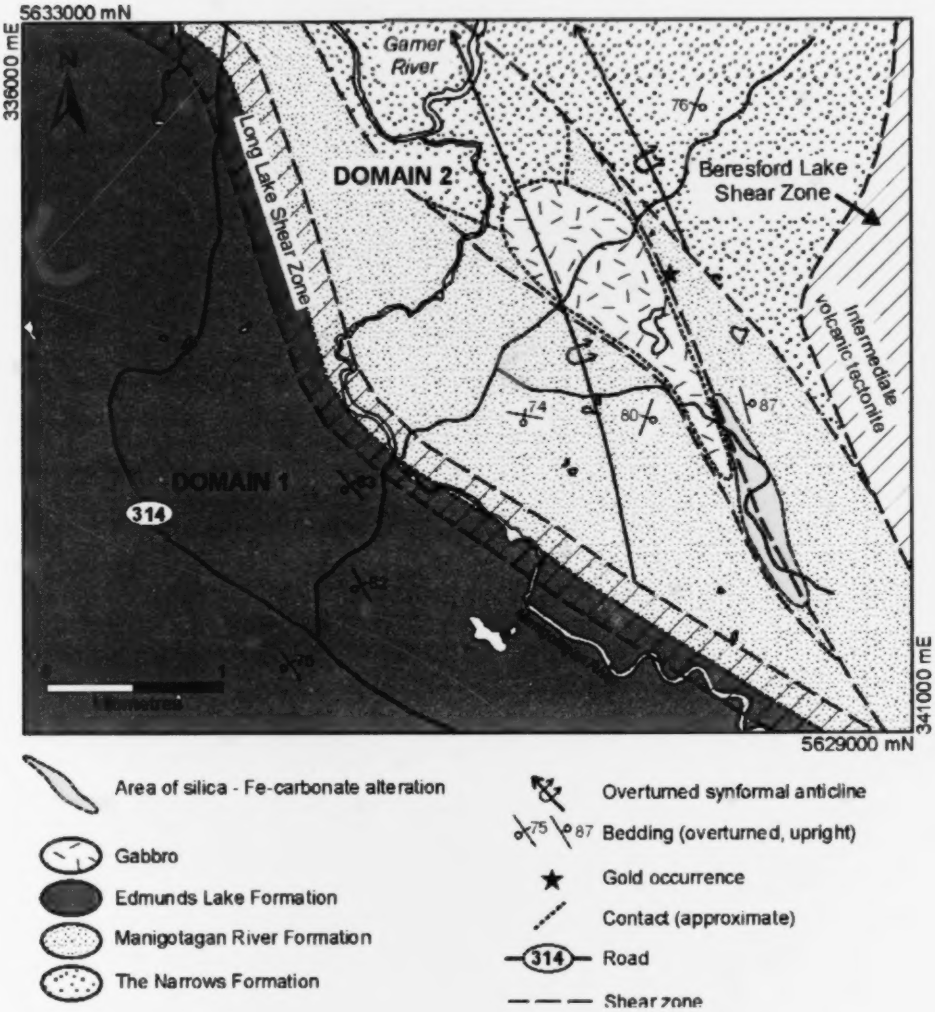

5633000 mN
336000 mE
N
Garner River
DOMAIN 2
Long Lake Shear Zone
Beresford Lake Shear Zone
Intermediate volcanic tectonite
76
74
80
87
DOMAIN 1
314
0
1
kilometres
341000 mE
5629000 mN
Area of silica - Fe-carbonate alteration
Gabbro
Edmunds Lake Formation
Manigotagan River Formation
The Narrows Formation
Overturned synformal anticline
75
87
Bedding (overturned, upright)
Gold occurrence
Contact (approximate)
314
Road
Shear zone

Figure GS-27-2: Simplified geology in the area of the Gem Lake logging road.

(Fig. GS-27-1).

The North Caribou Terrane (Thurston et al., 1991), which is bounded to the south by the regional-scale Wanipigow Fault, comprises ca. 3.0 Ga (Mesoarchean) basement plutonic rocks of mainly tonalitic composition, unconformably overlain by a ca. 2.9 Ga platform-rift sequence, and intruded by voluminous ca. 2.7 Ga (Neoarchean) granitoid plutons. The platform-rift sequence, as represented by the Lewis-Storey (Percival et al., 2001) and Wallace Lake assemblages (McRitchie, 1971; Sasseville and Tomlinson, 2000), is discontinuously exposed along the southern margin of the North Caribou Terrane (Fig. GS-27-1). The sequence typically consists of basal quartz arenitic rocks overlain by intercalated banded iron formation and komatiitic volcanic rocks, and is thought to record continental rifting at the southwest margin of the North Caribou Terrane (Percival et al., 2002).

The Manigotagan gneiss belt, which is bounded to the north by the regional-scale Manigotagan Fault, consists of paragneiss, orthogneiss and granitoid plutons. These rocks were derived, at least in part, from siliciclastic sequences in the adjacent Rice Lake belt, and underwent regional deformation and metamorphism at ca. 2.69 Ga, during the Kenoran orogeny.

The ca. 2.72 to 2.73 Ga (Turek et al., 1989) supracrustal rocks of the Rice Lake greenstone belt consist mainly of tholeiitic and calc-alkaline volcanic rocks of basaltic to rhyolitic composition, intercalated with thick synvolcanic mafic sills and minor derived volcaniclastic and epiclastic sedimentary rocks. These volcanic rocks are intruded by

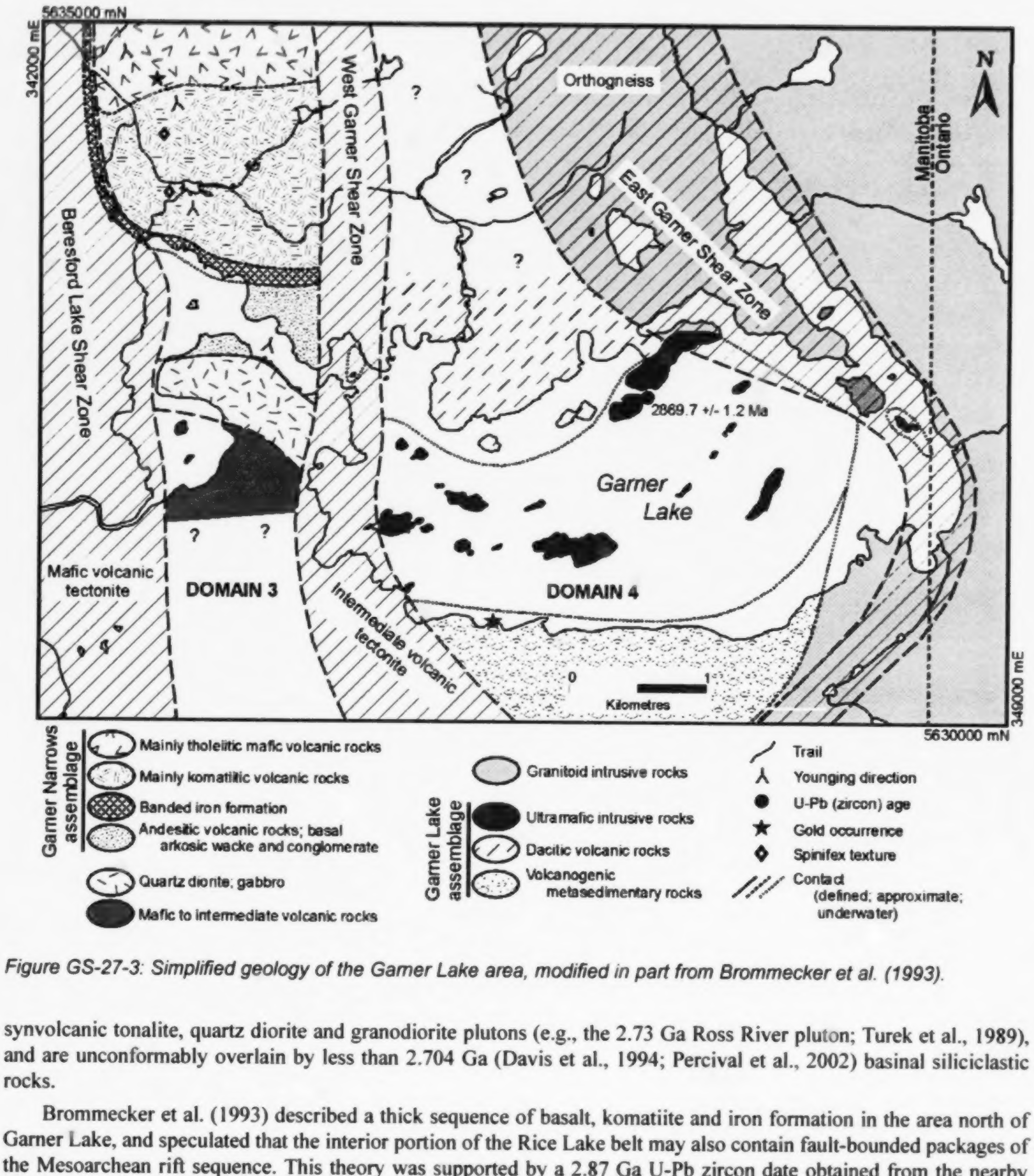

5635000 mN
342000 mE
N
Orthogneiss
West Garner Shear Zone
East Garner Shear Zone
Beresford Lake Shear Zone
Manitoba
Ontario
?
2869.7 +/- 1.2 Ma
Garner Lake
Mafic volcanic tectonite
DOMAIN 3
DOMAIN 4
Intermediate volcanic tectonite
0
1
Kilometres
349000 mE
5630000 mN
Garner Narrows assemblage
Mainly tholeiitic mafic volcanic rocks
Mainly komatiitic volcanic rocks
Banded iron formation
Andesitic volcanic rocks; basal arkosic wacke and conglomerate
Quartz diorite; gabbro
Mafic to intermediate volcanic rocks
Granitoid intrusive rocks
Garner Lake assemblage
Ultramafic intrusive rocks
Dacitic volcanic rocks
Volcanogenic metasedimentary rocks
Trail
Younging direction
U-Pb (zircon) age
Gold occurrence
Spinifex texture
Contact (defined; approximate; underwater)

Figure GS-27-3: Simplified geology of the Garner Lake area, modified in part from Brommecker et al. (1993).

synvolcanic tonalite, quartz diorite and granodiorite plutons (e.g., the 2.73 Ga Ross River pluton; Turek et al., 1989), and are unconformably overlain by less than 2.704 Ga (Davis et al., 1994; Percival et al., 2002) basinal siliciclastic rocks.

Brommecker et al. (1993) described a thick sequence of basalt, komatiite and iron formation in the area north of Garner Lake, and speculated that the interior portion of the Rice Lake belt may also contain fault-bounded packages of the Mesoarchean rift sequence. This theory was supported by a 2.87 Ga U-Pb zircon date obtained from the nearby Garner Lake layered ultramafic body (Poulsen et al., 1993), which Brommecker et al. (1993) considered to intrude the basal portion of the komatiite-bearing sequence. On this basis, Poulsen et al. (1996) subsequently defined the Garner Lake subgroup (Fig. GS-27-1), which they considered to be correlative with the Mesoarchean rocks at Wallace Lake. As demonstrated below, however, the geological picture in the Garner Lake area is significantly more complex than previously thought, and the local geological framework proposed by Poulsen et al. (1996) requires significant revision.

GENERAL GEOLOGY, STRATIGRAPHY AND METAMORPHISM

Four distinct stratigraphic-structural domains have been identified along the Gem Lake road–Garner Lake transect, each of which contains a distinctive association of rock types, locally with significant differences in the style and sequence of deformation. They trend north or northwest and are each bounded by major ductile shear zones. These domains, numbered 1 through 4 from west to east across the study area (Fig. GS-27-2, GS-27-3), are described in detail below.

Domain 1

Domain 1 consists of greywacke-mudstone turbidite of the Edmunds Lake Formation (Fig. GS-27-2). These rocks contain detrital zircons as young as 2.704 Ga (Davis et al., 1994), and regional stratigraphic relationships indicate that they unconformably overlie the ca. 2.73 Ga volcanic rocks of the Rice Lake belt.

This domain is bounded to the northeast by a 500 m thick ductile shear zone herein referred to as the 'Long Lake Shear Zone', after the location where it was originally described by Zwanzig (1971). The regional metamorphic mineral assemblage in these rocks consists of biotite-chlorite±hornblende and rare garnet, consistent with middle to upper greenschist facies peak metamorphic conditions.

Edmunds Lake Formation

The Edmunds Lake Formation consists of monotonously bedded greywacke-siltstone turbidite, with minor conglomerate, mudstone, chert and iron formation. Bedding in these rocks dips steeply northeast. Well-developed graded beds, channels, crossbedding and load structures indicate that these rocks face southwest, although local reversals are observed and indicate the presence of F_1 isoclinal folds. In general, the section appears to coarsen stratigraphically upward, with thin-bedded mudstone, iron formation and chert more common lower in the section, and thick-bedded greywacke and conglomerate more prevalent higher in the section. The greywacke is typically medium grained and contains less than 10% detrital quartz. Individual beds range up to 50 cm thick and exhibit normal size-grading and abundant slump-folds. Lenticular beds of polymictic conglomerate range up to 3 m thick and contain unsorted, typically subangular to well-rounded clasts that range in size up to 20 cm. In marked contrast to conglomerate in the underlying volcanic successions, clasts of phaneritic plutonic rock are an important component of the Edmunds Lake Formation conglomerate.

Domain 2

Domain 2 contains rocks of the Narrows Formation (Campbell, 1971; Weber, 1971) and the overlying Manigotagan River Formation (Owens and Seneshen, 1985; Seneshen and Owens, 1985), which represent the uppermost formations of the ca. 2.73 Ga (Turek et al., 1989) Bidou Lake subgroup. Although regional stratigraphic relationships point to a conformable relationship between these formations, the contact appears to be mainly tectonic in the mapped area. Domain 2 is bounded to the northeast by the ca. 2 km thick Beresford Lake Shear Zone, and to the southwest by the Long Lake Shear Zone (Fig. GS-27-2). Regional metamorphic mineral assemblages in these rocks comprise fine-grained chlorite-biotite±actinolite±sericite, consistent with lower greenschist facies peak metamorphic conditions.

Narrows Formation

The section of Narrows Formation exposed along the Gem Lake road consists of volcanic conglomerate, volcanic breccia and tuff breccia, intercalated with minor units of intermediate volcanic sandstone. Light grey to buff, aphanitic to plagioclase- and/or quartz-phyric, dacitic volcanic rock is the predominant clast type in the coarse fragmental rocks. The matrix consists of fine- to coarse-grained, plagioclase-crystal–rich, tuffaceous sandstone that contains up to 10% detrital quartz. The volcanic conglomerate is heterolithic and typically matrix supported, with well-rounded to subangular clasts that range in size up to 2 m, whereas the volcanic breccia is monolithic and clast supported, with angular to subrounded clasts generally less than 30 cm in size. A diffuse layering that dips steeply to the west-northwest is locally evident, and is defined by subtle variations in clast size and proportion of matrix. Load casts and channels observed in two locations indicate tops to the east-southeast.

Manigotagan River Formation

The Manigotagan River Formation, as originally defined by Seneshen and Owens (1985), is thought to mark the transition between the underlying Narrows Formation and the Edmunds Lake Formation. The section through the Manigotagan River Formation provided by the Gem Lake road is broadly similar to that described by Seneshen and Owens (1985), although considerably thicker due to structural thickening in the hinge of a macroscopic synformal anticline (Fig. GS-27-2). The hinge of this fold also contains a large body of medium-grained, homogeneous, leucocratic gabbro that discordantly intruded the Manigotagan River Formation (Fig. GS-27-2).

The section comprises mainly dark green to grey, aphyric to coarsely plagioclase-phyric, mafic to intermediate volcanic rocks, which include massive and pillowed flows, lapilli tuff, breccia and pillow breccia. The flows contain up to 5% round, quartz-filled amygdales, less than 0.5 cm in size, and locally display well-formed pillows less than 0.5 m in size. The volcanic rocks are intercalated with thick units of heterolithic volcanic conglomerate, with subordinate, thin-bedded units of fine-grained, chloritic, volcanic sandstone and mudstone, and minor chert. The finer grained clastic rocks contain well-developed graded bedding, with local load casts and channels. The conglomerate contains a diffuse metre-scale layering defined by variations in the proportion and size of clasts (Fig. GS-27-4). Typically, the clasts are subrounded to well rounded, equant and 10 to 30 cm in diameter, but locally range up to 2 m in maximum dimension. Texturally heterogeneous, generally plagioclase-phyric, intermediate volcanic rock accounts for more than 90% of the clast population, with minor clasts of mafic volcanic and sedimentary rock. The matrix consists of dark grey to green, coarse-grained chloritic sandstone that lacks detrital quartz.

Domain 3

Domain 3 contains the 'Garner narrows assemblage' (GNA), which is herein proposed for the generally west-trending, consistently north-facing sequence of rocks that is well exposed through the area of the narrows between the east and west portions of Garner Lake (Fig. GS-27-3). To the south, the GNA lies in apparent nonconformable contact with quartz diorite, which is flanked to the south by a thick package of mafic to intermediate volcanic rocks.

The northern, mafic volcanic portion of the GNA has previously been described by Brommecker et al. (1993), who documented the presence of komatiitic flows and suggested a possible correlation with Mesoarchean rift-sequence rocks elsewhere in the Uchi Subprovince. As described in detail below, the 2002 mapping has shown that the GNA contains all of the essential components that typify Mesoarchean rift sequences.

Domain 3 is bounded on the west by the Beresford Lake Shear Zone, and on the east by the approximately 500 m thick West Garner Shear Zone (the Garner Shear Zone of Poulsen et al., 1994). Metamorphic mineral assemblages comprise biotite-chlorite-actinolite±hornblende and rare garnet, consistent with middle to upper greenschist facies peak metamorphism.

Mafic to intermediate volcanic rocks

The southernmost portion of Domain 3 is underlain by a more than 1 km thick package of dark green to grey, mafic to intermediate volcanic rocks (Fig. GS-27-3). These rocks are typically aphyric to coarsely plagioclase-phyric, with up to 25% subhedral plagioclase crystals that are less than 0.5 cm in size and evenly distributed in an aphanitic to fine-grained matrix. The predominant rock type is monolithic tuff breccia that contains up to 50% angular to subrounded, plagioclase-phyric clasts that range in size up to 25 cm (generally 5–10 cm). The tuff breccia contains a diffuse layering and is locally intercalated with thin units of chloritic lapilli tuff; however, these rocks lack unambiguous younging criteria.

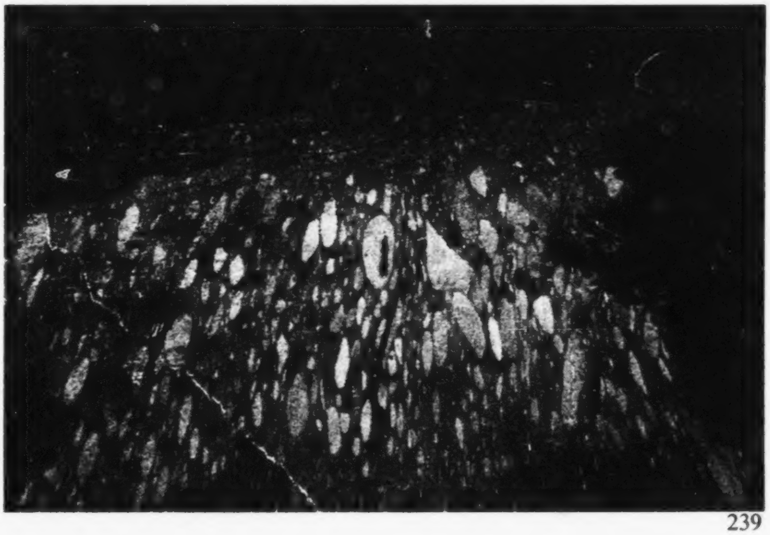


Figure GS-27-4: Metre-scale layering in volcanic conglomerate of the Manigotagan River Formation, exposed along the south branch of the Gem Lake logging road. This outcrop is located in the hinge of the macroscopic anticline shown in Figure GS-27-2. Note the orthogonal relationship between the layering and the regional S_2 foliation (parallel to pencil).

Quartz diorite and gabbro

To the north, the mafic to intermediate volcanic rocks lie in contact with an approximately 600 m thick body of quartz diorite and minor gabbro (Fig. GS-27-3). The gabbro is dark grey to green with a fine- to medium-grained, equigranular, ophitic texture and 20 to 50% plagioclase. The quartz diorite is dark grey, medium to coarse grained and texturally similar to the gabbro, although it contains greater than 50% plagioclase and up to 10% blue quartz. Coarse-grained to locally pegmatitic quartz diorite, which contains coarse-grained blue quartz and acicular hornblende crystals up to 2 cm in length, occurs in irregular patches and dike networks cutting the finer grained quartz diorite and gabbro, particularly near the northern contact. These rocks are crosscut by light grey to pink, fine- to medium-grained granodiorite dikes that range up to 1.5 m thick.

The southern contact of the quartz diorite has not been observed, and is therefore open to interpretation. An early, west-trending, high-strain zone is well exposed immediately south of the inferred contact (Fig. GS-27-3), which may indicate a wholly tectonic contact relationship. The apparent absence of granodiorite dikes in the volcanic rocks to the south may lend support to this interpretation. Alternatively, the contact may be intrusive and only slightly modified by later shearing. Additional mapping will be required to differentiate between these, or other, possibilities. The northern contact of the quartz diorite is comparatively well exposed, and is described below.

Garner narrows assemblage

Arkosic wacke and pebble conglomerate

The base of the GNA is marked by a distinctive unit of light grey to green, arkosic wacke and pebble conglomerate that ranges from 5 to 30 m thick. Typically, this unit consists of medium- to coarse-grained, pebbly arkosic wacke (Fig. GS-27-5) that contains up to 25% blue quartz. The blue quartz forms angular to subrounded, equant grains, less than 1 cm in size, that are evenly distributed in a fine- to medium-grained feldspathic matrix containing up to 30% chlorite, biotite, sericite and magnetite. These rocks are typically quite homogeneous on the scale of individual outcrops, although variations in the abundance and size of quartz grains in some outcrops locally define a very subtle, diffuse layering that parallels the strike of the unit. A coarser fragmental texture is apparent in many locations, and is defined by pebble- and cobble-sized clasts of phaneritic tonalite, evenly distributed in a finer grained matrix of chlorite, biotite and magnetite.

This unit is remarkably similar to the tonalitic 'grit', described by Percival et al. (2001, 2002), immediately below the basal unconformity of the Mesoarchean Lewis-Storey assemblage. They considered the grit to be a proximal erosional product of the immediately underlying tonalitic basement rocks. In the GNA, the coarse-grained, blue-quartz–bearing arkosic wacke lies in sharp contact with blue-quartz–bearing quartz diorite, which similarly suggests proximal derivation from the underlying plutonic rocks and therefore a nonconformable depositional relationship. Samples of the arkosic wacke and adjacent pegmatitic quartz diorite have been collected for U-Pb geochronology to test this hypothesis.

Andesitic volcanic rocks

The clastic unit lies in contact to the north with an approximately 800 m thick package of andesitic volcanic rocks. The contact between these units, as observed in three locations, is sharp and appears to be depositional (Fig. GS-27-6). The andesitic volcanic rocks are light green to grey, aphyric to plagioclase phyric and consist of intercalated tuff breccia, lapilli tuff and tuff, with minor units of thinly layered quartz arenite, iron carbonate and fine-grained ferruginous argillite. The fragmental volcanic rocks are monolithic and unsorted, with angular to subrounded clasts of light grey to green andesite that range in size up to 25 cm. Diffuse layering was observed in several locations, and trends generally east. The tuffaceous rocks are fine grained and homogeneous, with approximately 60% subhedral, felty-textured plagioclase laths, less than 1 mm in size, in an aphanitic feldspathic

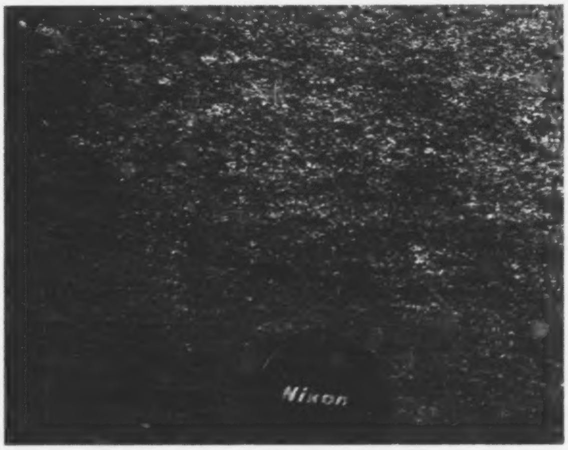


Figure GS-27-5: Coarse-grained pebbly arkosic wacke at the base of the Garner narrows assemblage, south shore of Garner narrows.

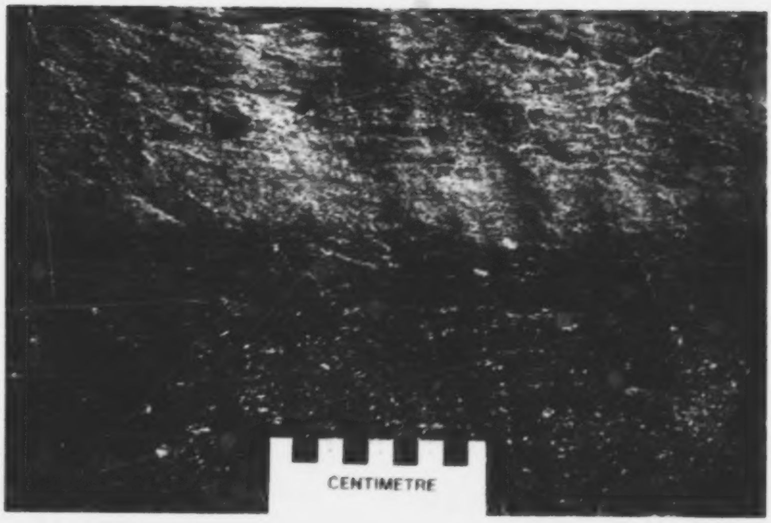


Figure GS-27-6: Sharp contact between dark grey, pebbly arkosic wacke and overlying, light grey-green, andesitic volcanic rocks of the Garner narrows assemblage, West Garner Shear Zone, north shore of Garner narrows.

matrix. A sample of relatively coarse plagioclase-phyric tuff was collected for U-Pb geochronology, with the goal of constraining the age of the andesitic volcanic rocks.

Banded iron formation

Through a gap in exposure less than 100 m wide, the andesitic volcanic rocks are flanked to the north by an approximately 150 m thick unit of banded oxide-facies iron formation (Fig. GS-27-3). These rocks consist of alternating layers, less than 10 cm thick, of light grey chert and fine-grained, granular magnetite, with accessory chlorite, quartz and biotite (Fig. GS-27-7). To the west, regional aeromagnetic data and field relationships indicate that the iron formation is transposed into the Beresford Lake Shear Zone (Fig. GS-27-3). To the east, the aeromagnetic signature becomes more diffuse, likely due to proximity to the Garner Lake ultramafic intrusive body.

Mafic volcanic rocks

As described by Brommecker et al. (1993), the iron formation is overlain by a thick (>1.5 km), north-facing section of predominantly massive and pillowed mafic flows, intercalated with rare, thin units of fine-grained sedimentary rocks and iron formation, and abundant gabbroic sills. Lithogeochemical data indicate that several, intercalated, compositional varieties of mafic flow are present, including calc-alkalic basalt, tholeiitic andesite, high-Mg tholeiitic basalt and komatiite (21–25% MgO, anhydrous; Brommecker et al., 1993). In general, the komatiitic rocks predominate in the southern portion of the section, whereas the tholeiitic rocks predominate farther to

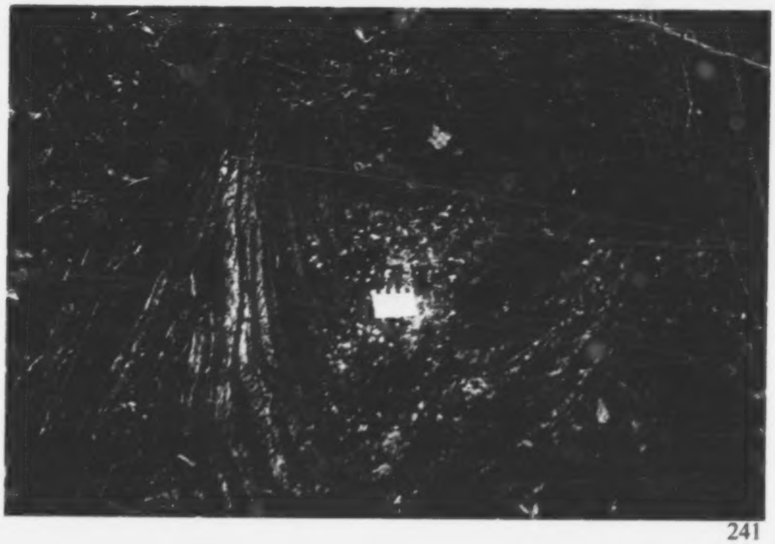


Figure GS-27-7: Banded iron formation in the Garner narrows assemblage (top of photo is north), north shore of Garner narrows. The east-trending layering in these rocks is folded by an F_3 fold, and transposed into a narrow D_3 shear zone along the west edge of the outcrop.

the north. Spinifex, autobreccia and polysuture textures are observed locally in the komatiitic rocks, thereby confirming their origin as volcanic flows (Brommecker et al., 1993).

Although several authors have indicated that the komatiite continues to the east across the trace of the West Garner Shear Zone (e.g., Corkery, 1995; Poulsen et al., 1996), the original work of Brommecker (1991) and Brommecker et al. (1993) provides little evidence to support this interpretation. The komatiitic section is therefore provisionally interpreted to be truncated at the West Garner Shear Zone (Fig. GS-27-3), pending additional mapping and lithogeochemical sampling in this key area.

Domain 4

Domain 4 contains the 'Garner Lake assemblage', herein proposed for the thick package of intermediate to felsic, volcanic and volcaniclastic rocks exposed along the north and south shores of Garner Lake, and which includes the Garner Lake layered ultramafic intrusion (Scoates, 1971), exposed mainly on islands in Garner Lake (Fig. GS-27-3).

The regional metamorphic mineral assemblage in the volcanic rocks comprises biotite-chlorite±garnet±hornblende, indicating upper greenschist to lower amphibolite facies peak metamorphic conditions. As described by Scoates (1971), a narrow contact-metamorphic aureole is developed along the north and south contacts of the Garner Lake intrusion, in which the volcanic rocks are strongly recrystallized and contain a coarse biotite-hornblende-epidote±garnet mineral assemblage, locally with up to 10% concentrically zoned, epidote-rich hornfels spots less than 15 cm in diameter. The presence of this aureole indicates an intrusive contact relationship between the ultramafic intrusion and the adjacent volcanic rocks. The nature of the contact relationship between the country rocks north and south of Garner Lake remains unknown.

Domain 4 is bounded to the west by the West Garner Shear Zone. To the east, the rocks of the Garner Lake assemblage are cut by multiple generations of granitoid plutonic rock, which include granite, granodiorite, hornblende tonalite and quartz diorite, and are transposed into a thick belt of mainly granitic orthogneiss that marks the trace of the East Garner Shear Zone (Fig. GS-27-3). Crosscutting relationships clearly show that at least some of the granitoid dikes intruded the Garner Lake ultramafic intrusion, as well as the volcanic country rocks, prior to development of the main gneissic fabric in the East Garner Shear Zone. The interior portion of the shear zone contains thick packages of intercalated felsic and mafic orthogneiss and garnet-biotite-hornblende straight gneiss (Fig. GS-27-8). The presumably high metamorphic grade and state of strain recorded by these rocks indicate that a significant strain and metamorphic gradient probably exists in this direction. It is also possible that some of these rocks represent allochthonous tectonic inclusions in the East Garner Shear Zone.

Garner Lake assemblage

Volcanogenic metasedimentary rocks

The south shore of Garner Lake was only briefly examined during the 2002 field season. As described by previous authors (e.g., Brommecker et al., 1993; Corkery, 1995, 1999; Poulsen et al., 1996), the section in this area

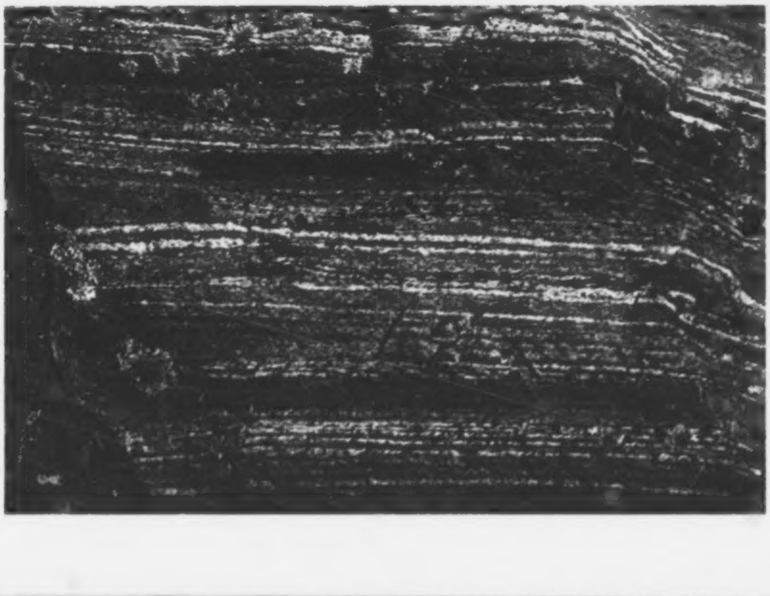


Figure GS-27-8: Garnet-biotite-hornblende straight gneiss in the East Garner Shear Zone, central part of the large island in eastern Garner Lake (see Fig. GS-27-3). Top of photo is northeast.

appears to consist mainly of volcanogenic metasedimentary rocks, with heterolithic volcanic conglomerate predominating in the examined outcrops. These rocks contain subangular to subrounded, unsorted clasts of mafic and intermediate volcanic material that range in size up to 40 cm. These clasts locally have aspect ratios of greater than 30:1 on horizontal outcrop surfaces, indicative of very high finite strain in this area.

Dacitic volcanic rocks

Outcrops along the northern shore of Garner Lake contain a well-exposed section of light grey, dacitic volcanic rocks more than 1 km thick. The predominant lithology is volcanic breccia and tuff breccia, with subordinate lapilli tuff and crystal tuff. The volcanic breccia units are characterized by a coarse, monolithic fragmental texture defined by very angular to subrounded, generally equant, unsorted fragments that range in size up to 25 cm. The fragments are clast supported, typically with less than 15% very fine grained, siliceous matrix material. The fragments consist of light grey, homogeneous, aphanitic to fine-grained dacite that contains up to 5% evenly distributed, subhedral plagioclase and/or hornblende crystals less than 3 mm in size. A diffuse, generally east-trending layering is locally present, although unambiguous facing criteria are lacking.

Garner Lake layered ultramafic intrusion

The main body of the ultramafic intrusion consists of 100 to 400 m thick, alternating layers of orange-brown–weathering serpentinized peridotite and dark grey-black clinopyroxenite. The layers strike generally east and northeast, and dip moderately to the north (Scoates, 1971). In the northeast portion of the intrusion, the clinopyroxenite contains significant volumes of heterogeneous gabbro, which ranges in texture and composition from fine- to medium-grained melanocratic gabbro, through medium- to coarse-grained leucogabbro, to pegmatitic leucogabbro and hornblende quartz diorite. The pegmatitic leucogabbro occurs as irregular segregation pods with diffuse contacts in clinopyroxenite and melagabbro, or as narrow (<2 m thick) dikes, locally with sharp, parallel contacts. The pegmatitic dikes appear to be generally concordant with the bulk-scale layering in the ultramafic rocks, and may therefore be more correctly described as sills. These rocks likely represent a late-stage magmatic segregation phase (e.g., Scoates, 1971), which formed largely in situ in the upper portion of the Garner Lake layered ultramafic intrusive body.

A sample of the pegmatitic material, processed for U-Pb geochronology, was found to contain colourless to brown zircons with high Th/U ratios characteristic of zircons crystallized from mafic magmas (Poulsen et al., 1993; Poulsen et al., work in progress, 1998). These zircons yielded a U-Pb zircon date of 2869.7 ± 1.2 Ma, which is considered to closely approximate the age of the Garner Lake ultramafic intrusion. This date confirms a 2.87 Ga (Mesoarchean) minimum age for the volcanic country rocks in the Garner Lake assemblage. Although Brommecker et al. (1993) suggested that the Garner Lake layered intrusion may represent the subvolcanic source of the komatiitic flows northwest of Garner Lake, field relationships indicate that these rocks are separated by the West Garner Shear Zone. Therefore, a direct link between these rocks is presently considered unlikely.

STRUCTURAL ANALYSIS

Previous structural studies in the eastern portion of the Rice Lake belt (e.g., Weber, 1971; Zwanzig, 1971; Brommecker, 1991; Sasseville and Tomlinson, 1999, 2000) all described three main generations of deformation structure, including 1) an early, layer-parallel, S_1 fabric that is axial planar to rare isoclinal folds; 2) a regional, northwest-trending, penetrative S_2 foliation that contains a prominent, steeply plunging L_2 elongation lineation and is axial planar to macroscopic, upright, variably plunging F_2 folds; and 3) northeast-trending kink folds, locally associated with an S_3 crenulation cleavage.

Within this framework, Brommecker (1991) defined a series of north-trending D_1 high-strain zones, including the Beresford Lake Shear Zone, which were thought to record early, layer-parallel thrusting. These shear zones were thought to predate ductile D_2 deformation structures formed during regional southwest-directed shortening and out-of-sequence thrusting. The D_3 deformation structures, which are mainly brittle, were thought to have formed during dextral strike-slip shear along the Wanipigow and Manigotagan faults, in a regime of regional northwest-directed shortening.

The sequence of deformation proposed by Brommecker (1991) appears to be broadly consistent with the deformation structures observed along the Gem Lake road–Garner Lake transect. However, Brommecker's interpretation of the Beresford Lake Shear Zone as a D_1 structure is difficult to reconcile with mesoscopic and macroscopic overprinting relationships, which clearly indicate that the main shear fabric postdates the regional S_2-L_2

fabric, as well as the macroscopic F_2 folds. This distinction may have important implications for gold exploration in the area, since overprinting relationships described by Brommecker (1991) indicate a pre- to syn-D_2 timing of gold mineralization in the southeast Rice Lake belt.

In the present study, mesoscopic deformation structures in the Garner Lake area are subdivided, on the basis of overprinting relationships, into four generations, which are interpreted to result from four discrete phases of ductile (D_1, D_2, D_3) and brittle-ductile (D_4) deformation. The major domain-bounding shear zones, including the Beresford Lake Shear Zone, are interpreted to have formed during the D_3 deformation phase, although it is still possible that an early movement history within these zones has been completely obliterated by subsequent deformation.

Deformation D_1

Structures attributed to D_1 deformation are only locally preserved in the study area. The hinges of F_2 folds and the microlithons between S_2 crenulation cleavage planes locally contain a penetrative S_1 foliation defined by a preferred orientation of fine-grained biotite and chlorite. This fabric is particularly evident in the Edmunds Lake Formation, in areas where it is oriented slightly oblique to bedding (S_0) and is crenulated by S_2. In these rocks, local reversals in younging direction that are not associated with a corresponding change in S_0-S_2 vergence indicate the presence of isoclinal F_1 folds. An early (pre-S_2) fabric defined by aligned plagioclase crystals is also locally evident in the large gabbroic intrusive body in the Manigotagan River Formation, although this may represent an igneous flow texture.

Deformation D_2

Structures attributed to D_2 deformation are regionally developed in the study area (e.g., Brommecker, 1991; Poulsen et al., 1996). The S_2 planar fabric is typically penetrative, finely spaced and defined by a preferred orientation of fine-grained biotite, chlorite and amphibole. In fragmental rocks, the S_2 foliation is defined by strongly flattened clasts (Fig. GS-27-4). Typically, the S_2 foliation dips steeply northeast or southwest and contains a downdip to steeply northwest-plunging mineral and stretching lineation (Fig. GS-27-9a), defined by the long axes of elongate mineral grains and stretched clasts (Fig. GS-27-10). The axial ratios of stretched clasts generally define oblate ellipsoids, consistent with flattening strains.

The S_2 foliation is axial planar to open to isoclinal, upright F_2 folds. In the Edmunds Lake Formation, S_0-S_2 intersection lineations indicate that the F_2 folds plunge steeply to the northwest. Regional-scale F_2 folds with amplitudes ranging up to several kilometres have been mapped northwest of the study area, and include the map-scale Beresford Lake anticline that defines the map pattern in the central portion of the Rice Lake belt (e.g., Campbell, 1971; Brommecker, 1991). A consistent S_0-S_2 angular relationship in the Edmunds Lake Formation along the Gem Lake road similarly indicates the presence of macroscopic F_2 folds southwest of the study area.

Discrete zones of syn-D_2 high strain are characterized by a penetrative mylonitic S_2 foliation that largely obliterates primary features in the rocks. This foliation contains a prominent L_2 mineral and stretching lineation, with local development of L>S tectonite in which the X:Y axial ratios of stretched clasts exceed 10:1. Isoclinal, rootless and intrafolial F_2 folds are common in these zones, and result from progressive folding and transposition during D_2 shearing. Particularly good examples of D_2 high-strain zones are found in Domain 3 along the southern contact of the quartz diorite (Fig. GS-27-3) and in dacitic volcanic rocks of Domain 4. Sense of shear indicators in the D_2 high-strain zones, as viewed in the X-Z plane of the strain ellipsoid, include shear bands, σ-porphyroclasts and asymmetric quartz boudins that consistently indicate northeast-side-up shear (Fig. GS-27-11). As suggested by Brommecker (1991), the geometry of D_2 deformation structures in the southeast Rice Lake belt appears to be compatible with regional southwest-directed shortening.

Deformation D_3

Ductile structures attributed to the D_3 deformation have a heterogeneous distribution and geometry. Outside of the major domain-bounding shear zones, the regional S_2 foliation is locally overprinted by a weak, steeply northwest-dipping S_3 crenulation cleavage that is defined by fine-grained, foliated chlorite and biotite. This cleavage is axial planar to steeply northwest-plunging, open, parallel-style F_3 folds (Fig. GS-27-9b) and crenulations.

Toward the margins of the major north-trending shear zones, the S_3 fabric intensifies and the F_3 folds become progressively more tight, asymmetric and similar in style. Along the margins of the Beresford Lake and West Garner shear zones, east-trending primary layering and the S_2-L_2 fabric are strongly transposed into tight to isoclinal F_3 folds that trend north and are markedly S-asymmetric (Fig. GS-27-12). In the interior of the shear zones, these folds are transposed by thick zones of chlorite-biotite schist and chloritic mylonite that contain intrafolial, S-asymmetric

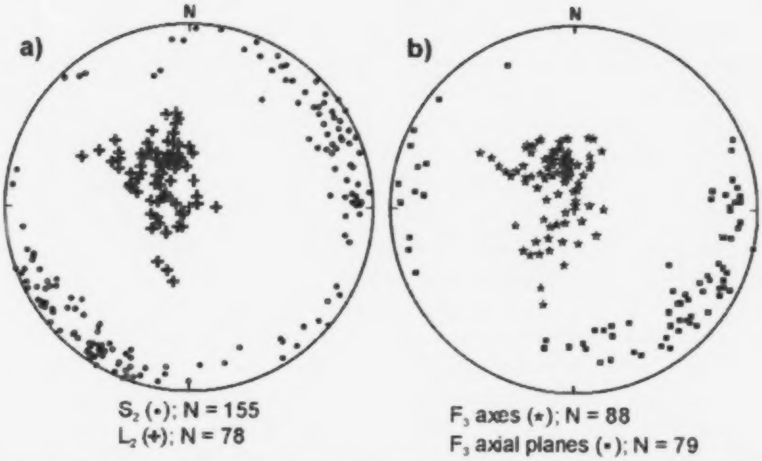


Figure GS-27-9: Lower hemisphere, equal area stereographic projections of the main deformation structures in the Garner Lake area: A) S_2 foliation (poles) and L_2 lineation; B) F_3 fold axes and poles to F_3 axial planes.

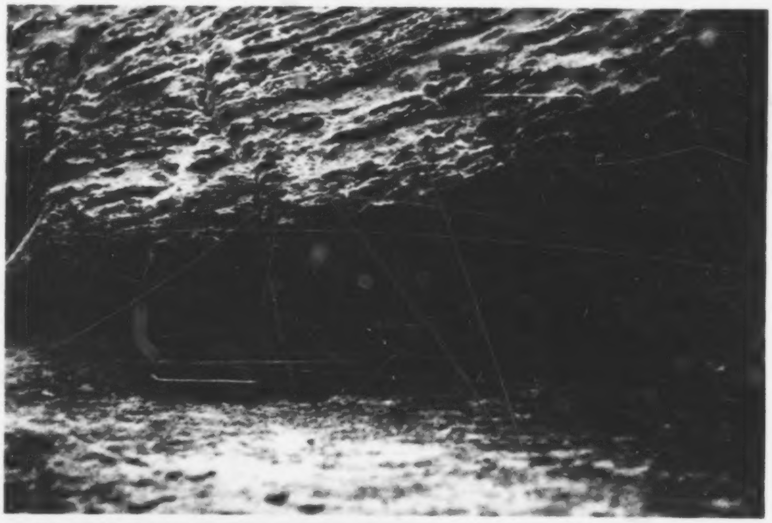


Figure GS-27-10: L_2 stretching lineation in intermediate volcanic rocks near the eastern margin of the West Garner Shear Zone (looking northwest), south shore of Garner narrows.

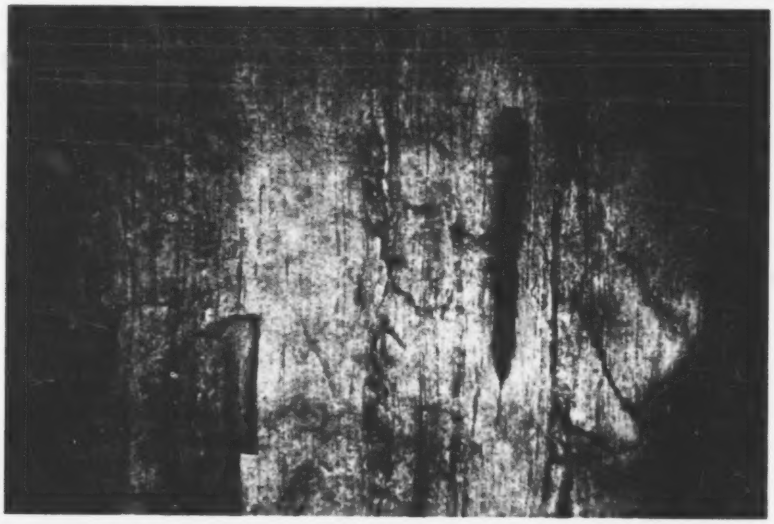
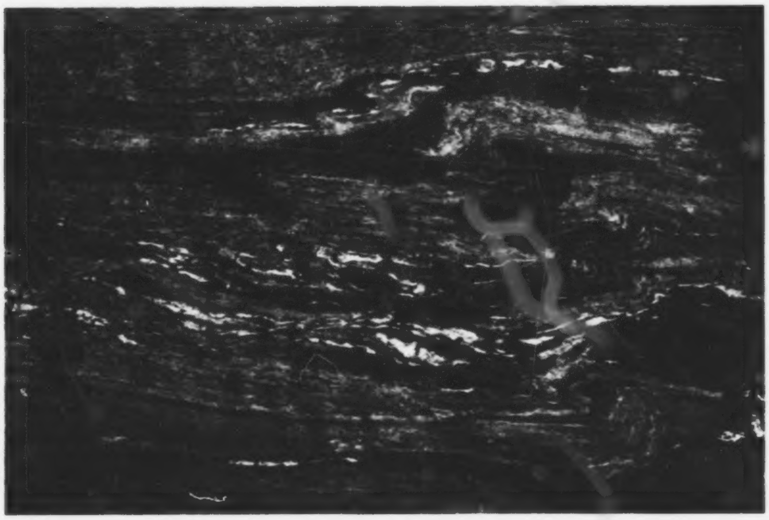


Figure GS-27-11: Penetrative S_2 foliation in andesitic tuff of the Garner narrows assemblage (looking southeast), north shore of Garner narrows. The asymmetric quartz boudins to the left of the pencil indicate northeast-side-up shear.

Figure GS-27-12: Asymmetric F_3 folds along the eastern margin of the Beresford Lake Shear Zone, western Garner Lake at the mouth of the Garner River. Note the sinistral shear bands in the left-centre portion of the photograph. Pencil points north.



isoclinal folds. Shear bands and asymmetric quartz boudins in these zones consistently indicate sinistral strike-slip shear (Fig. GS-27-13).

Collectively, these features indicate that the major north-trending, domain-bounding shear zones formed during D_3 deformation through progressive F_3 folding and transposition in a regime of sinistral shear. Northwest-directed shortening during the D_3 deformation, as proposed by Brommecker (1991), would be kinematically compatible with sinistral shear in the north-trending Beresford Lake and West Garner shear zones. The Long Lake Shear Zone, which contains dextral shear-sense indicators, trends generally west-northwest, and would thus be favourably oriented for dextral strike-slip shear during D_3 deformation.

Deformation D_4

The D_4 deformation structures are mainly brittle in character, and are heterogeneously developed. These structures typically comprise conjugate kink-fold and shear-fracture sets, which overprint D_3 structures in the Beresford Lake and West Garner shear zones. The shear fractures locally contain seams of fine-grained cataclasite less than 5 cm thick. The geometry and orientation of the conjugate fold and shear-fracture sets indicate that they formed in response to north-directed shortening of the D_3 shear zones.

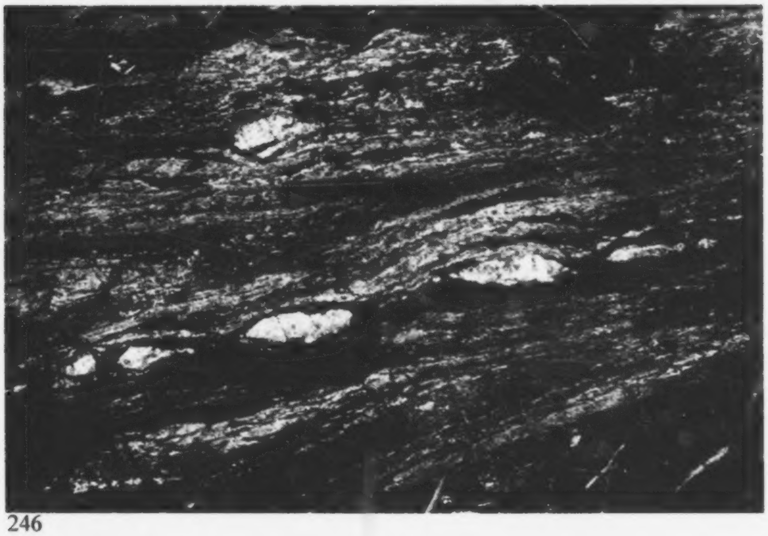


Figure GS-27-13: D_3 high-strain zone cutting iron formation in the northwest corner of Garner Lake. The asymmetric quartz boudins indicate sinistral shear. Pencil points north.

EXPLORATION CONSIDERATIONS

Results of 2002 fieldwork

The Garner Lake area contains thick successions of mafic to felsic volcanic rocks, including komatiite, that record heterogeneous, penetrative structural preparation during the regional D_2 deformation phase. Previous work in the central portion of the Rice Lake belt (e.g., Brommecker, 1991) and the Red Lake belt (e.g., Dubé et al., 2001) has demonstrated an intimate spatial association between gold mineralization and syn-D_2 high-strain zones. In this regard, D_2 high-strain zones that cut the volcanic successions in the Garner Lake area should be considered highly prospective for shear-hosted gold mineralization. The Mellow Yellow and Garner gold occurrences, as outlined below, may be examples of such mineralization.

A zone of potential economic significance has been identified along the southeast branch of the Gem Lake logging road. In this area, intermediate volcanic rocks of the Manigotagan River Formation are intruded by an elongate body of leucocratic gabbro, and have been folded by a macroscopic F_2 anticline (Fig. GS-27-2). The eastern limb of this fold and the S_2 foliation have been strongly transposed by a series of discrete, northwest-trending, D_3 shear zones that dip subvertically. The shear zones are marked by zones of strongly foliated chlorite schist, less than 10 m thick, that contain variably boudinaged quartz-carbonate-chlorite veins up to 0.5 m thick. Asymmetric quartz boudins and a pervasive shear-band fabric indicate dextral shear. The shear zones appear to have formed preferentially along the margins of the leucogabbro, and merge into a zone, greater than 100 m thick, beyond the southeastern termination of the intrusion.

The volcanic country rocks in this location locally weather light grey or deep reddish brown and contain patchy, irregular zones of moderate to strong, pervasive, silica–Fe-carbonate alteration. The more strongly silicified rocks have a dense, cherty appearance, with a fine-grained sugary texture and prominent conchoidal fracture. These rocks locally contain fine-scale stockworks of Fe-carbonate veins, less than 5 mm thick, or pervasive networks of chloritic fractures. Fresh broken surfaces reveal 1 to 2% finely disseminated pyrite and arsenopyrite. Thin (<30 cm) quartz veins with chlorite and/or Fe-carbonate selvages, less than 2 cm thick, constitute up to 5% of the altered outcrops. A channel sample of strongly silicified rock with less than 5% quartz veins returned 79 ppb Au and 396 ppm As, whereas an approximately 35 cm thick quartz vein in the same outcrop returned 58 ppb Au and 2140 ppm As.

The alteration has been traced along strike for more than 1 km, and is open in all directions. The only known gold occurrence in the area lies approximately 1.2 km to the north-northwest along strike, near the eastern sheared contact of the leucogabbro (Fig. GS-27-2). The showing consists of a very narrow (<50 cm thick) quartz vein that strikes north-northwest and has been traced for more than 75 m along strike (Assessment File 94326, Manitoba Industry, Trade and Mines, Winnipeg). The vein contains quartz and subordinate carbonate, chlorite, tourmaline and pyrite, with erratic gold values up to 27.4 g/t (AF 94326). The highest gold values are located in a right-lateral jog in the quartz vein, perhaps indicating that the auriferous hydrothermal solutions were preferentially channelled into sites of dilation in a regime of dextral shear.

Future work

The Garner Lake area contains two known high-grade gold occurrences that are targeted for detailed examination in the 2003 field season. The objective of this work will be to document the stratigraphic and structural setting of the gold mineralization and, in the context of the framework outlined above, provide insights into the mineralization process and controls. This information will be utilized to constrain predictive models for gold mineralization in the southeast Rice Lake belt.

The Garner occurrence (Theyer and Ferreira, 1990) is located along the south shore of Garner Lake (Fig. GS-27-3), and is marked by eight shallow prospect pits that expose three subparallel quartz veins hosted in strongly foliated, light grey, sericite-chlorite schist. A brief examination of the veins in 2002 revealed coarse visible gold in two locations, in keeping with a grab-sample assay result of 61 g/t Au reported by Theyer and Ferreira (1990). In 1980, Esso Resources Canada Inc. completed seven drillholes, totalling 492 m, based on channel-sample results of 14.1 g/t Au across a 1.5 m width and over a length of 35 m along strike (Assessment File 93330, Manitoba Industry, Trade and Mines, Winnipeg). Although the results of this drilling were essentially negative, the structural attributes of this showing have never been examined in detail.

The second gold occurrence is the Mellow Yellow showing (Assessment File 93694, Manitoba Industry, Trade and Mines, Winnipeg), located approximately 1 km north of the western arm of Garner Lake (Fig. GS-27-3). The showing consists of thin, lenticular quartz veins and stringers in sheared gabbro that returned assays of up to 77.5 g/t Au from grab samples (AF 93694). Brommecker (1996) indicated that the showing is hosted by a strongly sheared gabbro sill, more than 25 m thick, in a northwest-facing section of massive tholeiitic mafic flows and minor iron formation, immediately adjacent to the upper contact of the underlying komatiitic volcanic rocks (Fig. GS-27-3). In this area, the rocks contain an early, layer-parallel foliation that is transposed to the west by the D_3 Beresford Lake Shear Zone. Near the showing, the early fabric is cut by a series of subsidiary D_3 shear zones and feldspar or quartz porphyritic dikes that generally trend north (Brommecker, 1996). Interestingly, the stratigraphic and structural setting of this gold occurrence are quite similar to those described by Dubé et al. (2001) for the Campbell–Red Lake deposit in the Red Lake belt.

ACKNOWLEDGMENTS

Paul Kremer provided capable and enthusiastic assistance in the field, despite the often difficult working conditions. Neill Brandson, Doug Berk, Karen Punstel, Ric Unruh, Gerry Benger and Vio Varga provided logistical support over the course of the summer. Al Bailes and Tim Corkery are acknowledged for numerous discussions regarding the geology of the Rice Lake belt. Tim Corkery is thanked for narrowly preventing the theft of two propane refrigerators by a remarkably persistent, marauding bear.

REFERENCES

Brommecker, R. 1991: The structural setting of gold occurrences in the southeast Rice Lake greenstone belt, southeast Manitoba; M.Sc. thesis, Queen's University, Kingston, Ontario, 267 p.

Brommecker, R. 1996: Geology of the Beresford Lake area, southeast Manitoba; Geological Survey of Canada, Open File 3318, 127 p.

Brommecker, R., Poulsen, K.H. and Hodgson, J.C. 1989: Preliminary report on the structural setting of gold at the Gunnar mine in the Beresford Lake area, Uchi Subprovince, southeastern Manitoba; *in* Current Research, Part C, Geological Survey of Canada, Paper 89-1C, p. 325–332.

Brommecker, R., Scoates, R.F.J. and Poulsen, K.H. 1993: Komatiites in the Garner Lake–Beresford Lake area: implications for tectonics and gold metallogeny of the Rice Lake greenstone belt, southeast Manitoba; *in* Current Research, Part C, Geological Survey of Canada, Paper 93-1C, p. 259–264.

Campbell, F.H.A. 1971: Stratigraphy and sedimentation of part of the Rice Lake Group, Manitoba; *in* Geology and Geophysics of the Rice Lake Region, Southeastern Manitoba (Project Pioneer), W.D. McRitchie and W. Weber (ed.), Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 71-1, p. 135–188.

Corkery, M.T. 1995: Geologic mapping in the Garner Lake–Beresford Lake area of the Rice Lake greenstone belt; *in* Report of Activities 1995, Manitoba Energy and Mines, Geological Services, p. 136–139.

Corkery, M.T. 1999: Reassessment of major geologic boundaries in the southeast Rice Lake greenstone belt; *in* Report of Activities 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 111–113.

Davis, D.W., Brommecker, R., Scoates, R.F.J. and Poulsen, K.H. 1994: Report on the geochronology of rocks from the Rice Lake belt, Manitoba; unpublished report, Royal Ontario Museum, Geology Department.

Dubé, B., Williamson, K. and Malo, M. 2001: Preliminary report on the geology and controlling parameters of the Goldcorp Inc. High Grade zone, Red Lake mine, Ontario; Geological Survey of Canada, Current Research 2001-C18, 23 p.

Lau, M.H.S. 1988: Structural geology of the vein system in the San Antonio gold mine, Bissett, Manitoba, Canada; M.Sc. thesis, University of Manitoba, Winnipeg, 154 p.

McRitchie, W.D. 1971: Geology of the Wallace Lake–Siderock Lake area: a reappraisal; *in* Geology and Geophysics of the Rice Lake Region, Southeastern Manitoba (Project Pioneer), W.D. McRitchie and W. Weber (ed.), Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 71-1, p. 107–125.

Owens, D.J. and Seneshen, D.M. 1985: Stormy Lake (part of 52L/14SW); Manitoba Energy and Mines, Geological Services, Preliminary Map 1985 R-1, scale 1:10 000.

Percival, J.A., Bailes, A.H. and McNicoll, V. 2001: Mesoarchean western margin of the Superior Craton in the Lake Winnipeg area, Manitoba; Geological Survey of Canada, Current Research 2001-C16, 19 p.

Percival, J.A., Bailes, A. and McNicoll, V. 2002: Mesoarchean breakup, Neoarchean accretion in the western Superior craton, Lake Winnipeg, Canada; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Saskatoon, Saskatchewan, May 30–June 2, 2002, Field Trip B3 Guidebook, 42 p.

Poulsen, K.H., Davis, D.W., Weber, W. and Scoates, R.F.J. 1993: Geological and geochronological studies in the Rice Lake Belt; *in* Report of Activities 1993, Manitoba Energy and Mines, Geological Services, p. 152.

Poulsen, K.H., Weber, W., Brommecker, R. and Seneshen, D.N. 1996: Lithostratigraphic assembly and structural setting of gold mineralization in the eastern Rice Lake greenstone belt, Manitoba; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Winnipeg, Manitoba, May 27–29, 1996, Field Trip A4 Guidebook, 106 p.

Poulsen, K.H., Weber, W., Garson, D.F. and Scoates, R.F.J. 1994: New geological observations in the Rice Lake belt, southeastern Manitoba; *in* Report of Activities 1994, Manitoba Energy and Mines, Geological Services, p. 163–166.

Richardson, D.J. and Ostry, G. 1996: Gold deposits of Manitoba; Manitoba Energy and Mines, Economic Geology Report ER86-1 (second edition), 114 p.

Sanborn-Barrie, M., Skulski, T. and Parker, J. 2001: Three hundred million years of tectonic history recorded by the Red Lake greenstone belt, Ontario; Geological Survey of Canada, Current Research 2001-C19, 19 p.

Sanborn-Barrie, M., Skulski, T., Parker, J. and Dubé, B. 2000: Integrated regional analysis of the Red Lake greenstone belt and its mineral deposits, western Superior Province, Ontario; Geological Survey of Canada, Current Research 2000-C18, 16 p.

Sasseville, C. and Tomlinson, K.Y. 1999: Geology of the Mesoarchean Wallace Lake greenstone belt, southeastern Manitoba; *in* Current Research 1999-C, Geological Survey of Canada, p. 179–186.

Sasseville, C. and Tomlinson, K.Y. 2000: Tectonostratigraphy, structure, and geochemistry of the Mesoarchean Wallace Lake greenstone belt, southeastern Manitoba; Geological Survey of Canada, Current Research 2000-C14, p. 1–9.

Scoates, R.F.J. 1971: Ultramafic rocks of the Rice Lake greenstone belt; *in* Geology and Geophysics of the Rice Lake Region, Southeastern Manitoba (Project Pioneer), W.D. McRitchie and W. Weber (ed.), Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 71-1, p. 189–201.

Seneshen, D.M. and Owens, D.J. 1985: Geological investigations in the Stormy Lake area; *in* Report of Field Activities 1985, Manitoba Energy and Mines, Geological Services / Mines Branch, p. 112–119.

Stephenson, J.F. 1972: Gold deposits of the Rice Lake–Beresford Lake area, southeastern Manitoba; Ph.D. thesis, University of Manitoba, Winnipeg, 294 p.

Stockwell, C.H. 1940: Gold mines and prospects in the Rice Lake–Beresford Lake area, Manitoba; Transactions of the Canadian Institute of Mining and Metallurgy, v. 43, p. 613–626.

Theyer, P. 1991: Mineral deposits and occurrences in the Aikens Lake area, NTS 52M/3; Manitoba Energy and Mines, Geological Services, Mineral Deposit Series, Report No. 15, 108 p.

Theyer, P. 1994a: Mineral deposits and occurrences in the Bissett area, NTS 52M/4; Manitoba Energy and Mines, Geological Services, Mineral Deposit Series, Report No. 18, 101 p.

Theyer, P. 1994b: Mineral deposits and occurrences in the Flintstone Lake area, NTS 52L/11; Manitoba Energy and Mines, Geological Services, Mineral Deposit Series, Report No. 22, 60 p.

Theyer, P. and Ferreira, K.J. 1990: Mineral deposits and occurrences in the Garner Lake area, NTS 52L/14; Manitoba Energy and Mines, Minerals Division, Mineral Deposit Series, Report No. 10, 173 p.

Theyer, P. and Yamada, P.H. 1989: Mineral deposits and occurrences in the Manigotagan Lake area, NTS 52L/13; Manitoba Energy and Mines, Minerals Divison, Mineral Deposit Series Report No. 4, 108 p.

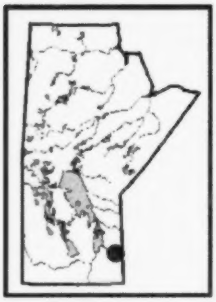
Thurston, P.C., Osmani, I.A. and Stone, D. 1991: Northwestern Superior Province: review and terrane analysis; *in* Geology of Ontario, P.C. Thurston, H.R. Williams, R.H. Sutcliffe and G.M. Stott (ed.), Ontario Geological Survey, Special Volume 4, pt. 1, p. 81–144.

Turek, A., Keller, R., Van Schmus, W.R. and Weber, W. 1989: U-Pb zircon ages for the Rice Lake area, southeastern Manitoba; Canadian Journal of Earth Sciences, v. 26, p. 23–30.

Weber, W. 1971: Geology of the Long Lake–Gem Lake area; *in* Geology and Geophysics of the Rice Lake Region, Southeastern Manitoba (Project Pioneer), W.D. McRitchie and W. Weber (ed.), Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 71-1, p. 63–106.

Whiting, B.H. and Sinclair, A.J. 1990: Variation of gold content with depth in the San Antonio gold mine; Canadian Institute of Mining and Metallurgy Bulletin, v. 83, no. 941, p. 43–46.

Zwanzig, H.V. 1971: Structural geology at Long Lake, Manitoba; *in* Geology and Geophysics of the Rice Lake Region, Southeastern Manitoba (Project Pioneer), W.D. McRitchie and W. Weber (ed.), Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 71-1, p. 285–298.



GS-28 PLATINUM GROUP ELEMENT INVESTIGATIONS IN THE PETERSON BLOCK OF THE BIRD RIVER SILL (NTS 52L5NE), MANITOBA

by P. Theyer

Theyer, P. 2002: Platinum group element investigations in the Peterson Block of the Bird River Sill (NTS 52L5NE), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 250–254.

SUMMARY

The Bird River Sill, a repository of significant chromite resources, supported two nickel-copper mines and, in the past decade, has been explored for platinum group elements (PGE). In the southern part of the sill, exploration concentrated on the Chrome property and, to a lesser degree, on the Page property. Significant PGE concentrations discovered in 2001 brought the 'Peterson Block', which is located between the Chrome and Page properties, to the attention of explorationists. In the Peterson Block, the Lamprey Falls Formation consists of massive and pillowed basalt interlayered with and crosscut by abundant coarse-grained synvolcanic 'gabbroic' sills and dikes. The formation is locally characterized by abundant fracture-bound pyrrhotite. Sulphide minerals exposed in a number of pits and trenches are, in places, associated with strong silicification and have locally attracted intense exploration. Because exploration records indicate that samples collected from these trenches were not analyzed for PGE, a number of rock samples were collected from mineralized zones and are currently being analyzed for Pt, Pd and Au.

INTRODUCTION

Approximately two weeks were spent investigating the Peterson Block of the Bird River Sill (Fig. GS-28-1). Substantial concentrations of Pt and Pd were discovered in a drillhole that intersected mineralized peridotite (K. McMurren, pers. comm., 2001). Core logging in 2001 showed that the PGE were associated with massive pyrrhotite and minor chalcopyrite accumulations in fractures. This work also determined that all four holes intersected lithologically different peridotite. Field inspections showed that peridotite occurs adjacent to the stratigraphic base of the Bird River Sill and is associated with feldspathic peridotite of the 'Contact Zone'. This lowermost unit of the sill is in contact with basalt and gabbro of the stratigraphically underlying Lamprey Falls Formation (Scoates, 1983).

The Lamprey Falls Formation consists principally of mafic volcanic rocks interlayered with and crosscut by hypabyssal coarse-grained gabbroic intrusions. Abundant brittle fractures are mineralized with silica and/or sulphide minerals. The most prominent of these mineralized fracture zones strikes east-southeast and has been traced for more than 150 m, in a number of pits and trenches. Trees growing in some of these exploration workings are more than 60 years old. This and several other mineralized zones in the Lamprey Falls Formation were sampled in 2002 and are currently being analyzed for PGE. The most recent geological investigation of this area was by Falconbridge Ltd. in 1981 (Assessment File 92649, Manitoba Industry, Trade and Mines, Winnipeg). Samples were not analyzed for PGE at that time, and it is assumed that prospectors active prior to 1981 would also have not analyzed for these elements.

GALAXY PGE OCCURRENCE

The Galaxy occurrence is partly exposed in an east-southeast-striking trench, measuring approximately 17 m long by 1 m wide by 0.5 m deep, that is underlain by grey-green–weathering serpentinized peridotite. The host peridotite is intensely sheared, with a vertically dipping fabric that strikes approximately 120°. Four holes were drilled in 2000 and 2001.

Drillhole G1

This hole, oriented 335°/45°, is 20.5 m long. From the collar to a depth of 12 m, it intersected dunite consisting of subrounded, densely packed, millimetre-size olivine crystals. Pyrrhotite occurs, in places, as pseudomorphs after olivine and as fracture coatings. A pebble-shaped chromitite agglomeration, measuring approximately 2 cm in diameter, was intersected at approximately 9.7 m. Pyroxene concentration increases gradually from trace amounts to more than 20% at about 11 m. The highest concentration of sulphide minerals intersected, at a depth of 13 m, consists of a 10 cm long interval containing approximately 8% pyrrhotite, in places associated with wispy traces of coarse-grained clusters and fracture-filling chalcopyrite.

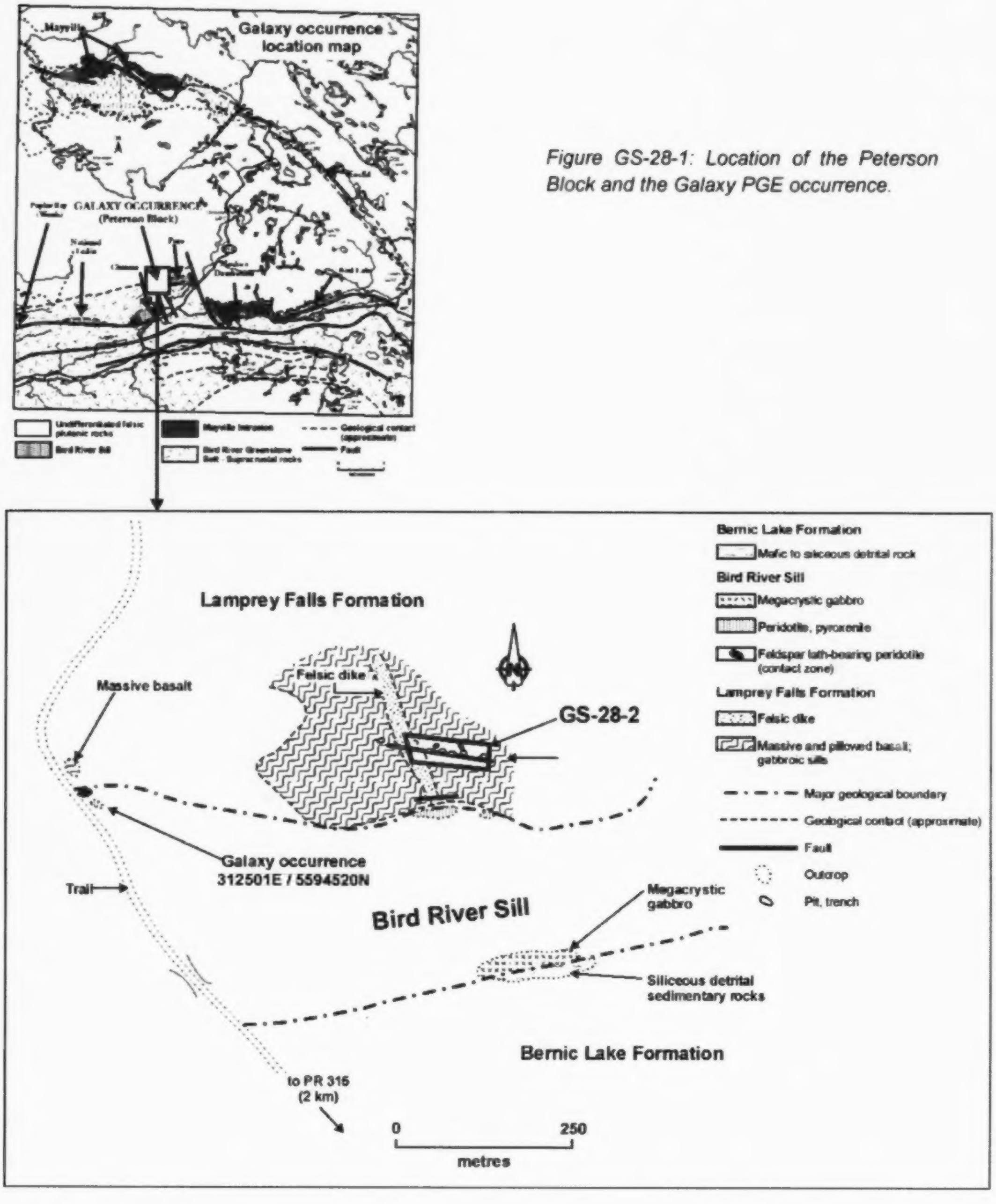

Galaxy occurrence location map
Mayville
GALAXY OCCURRENCE
(Peterson Block)
Undifferentiated felsic plutonic rocks
Bird River Sill
Mayville Intrusion
Bird River Greenstone Belt - Supracrustal rocks
Geological contact (approximate)
Fault
Lamprey Falls Formation
Massive basalt
Felsic dike
GS-28-2
Galaxy occurrence
312501E / 5594520N
Trail
Bird River Sill
Megacrystic gabbro
Siliceous detrital sedimentary rocks
Bernic Lake Formation
to PR 315
(2 km)
0
250
metres
Bernic Lake Formation
Mafic to siliceous detrital rock
Bird River Sill
Megacrystic gabbro
Peridotite, pyroxenite
Feldspar lath-bearing peridotite (contact zone)
Lamprey Falls Formation
Felsic dike
Massive and pillowed basalt; gabbroic sills
Major geological boundary
Geological contact (approximate)
Fault
Outcrop
Pit, trench

Figure GS-28-1: Location of the Peterson Block and the Galaxy PGE occurrence.

Drillhole G2

This hole, oriented 022°/45°, is 19.5 m long. The core is characterized by four well-defined, decimetre-long mineralized zones hosted by homogeneous peridotite. Barren peridotite intersected at and below the collar of the hole is mineralized from a depth of approximately 60 to 70 cm with up to 5% pyrrhotite and trace chalcopyrite. The mineralization occurs principally as massive veins and minor fracture fillings. The next intensely mineralized intersection occurs at a depth of approximately 1.5 m. It is separated from the previous mineralized zone by barren peridotite. This mineralized zone consists of approximately 30 cm of up to 8% pyrrhotite and minor chalcopyrite concentrated in fractures. The mineralization decreases to approximately 2% disseminated pyrrhotite and, at approximately 4 m depth, the core is barren of sulphide minerals. A third mineralized zone, with up to 5% pyrrhotite, occurs between depths of 5.3 and 6 m. The core between depths of 6 m and approximately 7.3 m is mineralized with approximately 1% pyrrhotite. At 7.3 m, pyrrhotite concentrations rise abruptly to form the fourth mineralized zone, with more than 50% pyrrhotite over approximately 15 cm and then gradually declining to trace sulphide mineralization at 9.5 m. The drillhole ends in massive serpentinized peridotite that contains trace disseminated pyrrhotite.

Drillhole G3

This hole, oriented 202°/45°, is 13.4 m long. It intersected pyroxenite characterized by intensely silicified intervals. Pyrrhotite occurs as minor fracture fillings and in small millimetre-size clusters, but never exceeding approximately 3% of the core. Massive, fine-grained, dark grey, barren rocks interpreted as basalt were intersected from a depth of 9.1 m to the end of the hole.

Drillhole G4

This hole, drilled vertically, is 9.1 m long. It intersected pyroxenite and peridotite mineralized with traces of pyrrhotite, except for the interval between 7.6 and 7.9 m, where a brittle fracture is mineralized with up to 3% pyrrhotite and trace pyrite.

Despite the fact that all four holes were collared at virtually the same location, the presence of different rock types suggests that they intersected different parts of the ultramafic sequence of the sill.

Platinum concentrations range from 13 to 774 ppb and palladium concentrations range from 83 to 3490 ppb. The Pt-Pd ratio fluctuates from sample to sample, with the average ratio of all samples being 1:3.8. This ratio is substantially greater than the approximately 1:2.5 (Pt:Pd) ratio from a set of samples collected across the entire Ultramafic Series exposed on the Chrome property of the sill (Theyer, 1985). The latter ratio was corroborated by the results published by Hulbert (1988). All samples returned anomalously elevated concentrations of Pt and Pd, defined here as a combined Pt+Pd concentration exceeding 100 ppb. The highest concentrations were intersected in drillhole G2, where four discrete intersections of massive pyrrhotite and minor chalcopyrite are hosted by fractured zones in peridotite.

DISCUSSION

The Galaxy PGE occurrence is hosted by peridotite of the Ultramafic Series of the Bird River Sill, closely associated with feldspathic peridotite of the 'Contact Zone'. This suggests that the Galaxy mineralization occurs at or near the stratigraphic base of the Ultramafic Series of the sill. Elevated PGE concentrations hosted by peridotite in a comparable stratigraphic location are known elsewhere in the sill, such as on the Page property (Theyer, 2001; Theyer et al., 2001) and the Chrome property (Theyer, 1985). It is suggested that Ultramafic Series of the sill close to the contact with the underlying basaltic rocks of the Lamprey Falls Formation is an underexplored target in the search for PGE.

INVESTIGATIONS IN THE LAMPREY FALLS FORMATION

The Lamprey Falls Formation (Trueman, 1980), consisting of basalt and related subvolcanic gabbro, stratigraphically underlies the Bird River Sill. It is characterized by massive, fine-grained and dark grey–weathering basalt and pillowed flows containing pillows, amoeboid pillows and pillow breccias. Some pillows are metre size and well preserved, with south-facing tops. Parallel to subparallel with the flows are intercalated, mafic, coarse-grained, subvolcanic 'gabbroic' sills, ranging from 1 to 5 m in thickness. Numerous observations of gabbroic material intruding, disrupting and, in places, fragmenting the basalt suggest that at least some of the gabbroic phase intruded late and brittly fractured the basalt.

Sulphide mineralization (disseminated pyrrhotite) is widespread and occurs as a profusion of rusty outcrops in the Peterson Block area. Most prominent is a southeast-striking fracture investigated by a number of pits and trenches (Fig. GS-28-2). Most of the excavations are filled with overburden and overgrown with trees and shrubs estimated to be at least 60 years old. The mineralization is centred along a fault and consists of pyrrhotite, pyrite and thin layers of massive chalcopyrite and magnetite. A well-exposed trench near a felsic dike displays a symmetric mineralization pattern dominated by sulphide in the centre and grading into silicification toward the edges. The edge of the mineralization consists of weakly silicified basalt that becomes beige to brownish, high-purity silica rock within a distance of 0.5 m. This rock is mineralized with gradually increasing amounts of disseminated pyrrhotite. Together with increasing amounts of pyrrhotite, there is a parallel increase in planar orientation that eventually results in a fabric characterized by intense banding. The centre of the mineralization consists of a prominently banded to massive

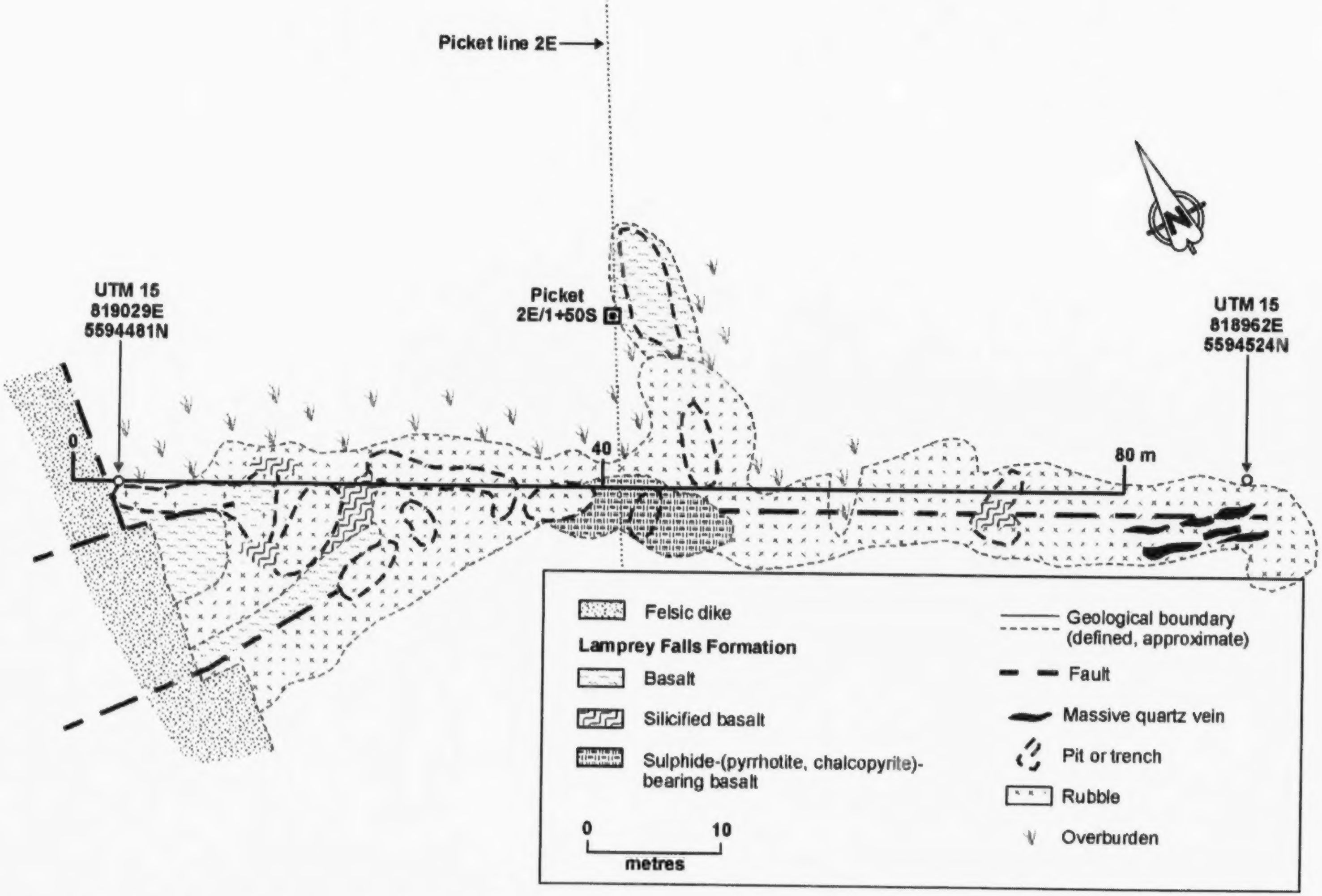

Picket line 2E
UTM 15
819029E
5594481N
Picket
2E/1+50S
UTM 15
818962E
5594524N
0
40
80 m
N
Felsic dike
Lamprey Falls Formation
Basalt
Silicified basalt
Sulphide-(pyrrhotite, chalcopyrite)-bearing basalt
0
10
metres
Geological boundary (defined, approximate)
Fault
Massive quartz vein
Pit or trench
Rubble
Overburden

Figure GS-28-2: Geological sketch map of the mineralized vein, showing the location of trenches and mineralization types.

pyrrhotite unit, approximately 40 cm thick, that is interlayered with a number of millimetre-thick chalcopyrite layers. This mineralization and its textures are mirrored on the opposite side of the vein.

DISCUSSION

Any sulphides present in mafic-ultramafic rocks may have been exposed to and concentrated PGE. Sulphide mineralization in the mafic volcanic rocks of the Lamprey Falls Formation is therefore a target of interest for PGE exploration. Moreover, it is well established that PGE are mobile, especially in fluid-rich, saline environments (Olivo and Gauthier, 1994; Distler et al., 2002). This is important, considering the proximity of the sulphide-bearing rocks in the Lamprey Falls Formation to the PGE-bearing rocks of the Bird River Sill.

ACKNOWLEDGMENTS

The author would like to acknowledge J. Sopotiuk, F. Sellers and K. McMurren for allowing him to log their drill core and results of geochemical investigations of the Galaxy prospect. He would also like to acknowledge the cooperation of J. Campbell, who provided geological and geophysical documentation and numerous discussions on the geology of his property.

REFERENCES

Distler, V., Yudovskaya, M., Chaplygin, I. and Znamensky, V. 2002: PGE in the modern hydrotherms of Kudryavy Volcano (Kuril Islands); 9th International Platinum Symposium, Extended Abstracts, Billings, Montana.

Hulbert, L.J. 1988: Geological environments of the platinum group elements; Geological Survey of Canada, Open File 1440, 148 p.

Olivo, G.R. and Gauthier, M. 1994: Palladian gold from the Cauê iron mine, Itabira District, Minas Gerais, Brazil; Mineralogical Magazine, v. 58, p. 579–587.

Scoates, R.F.J. 1983: A preliminary stratigraphic examination of the ultramafic zone of the Bird River Sill, southeastern Manitoba; *in* Report of Field Activities 1983, Manitoba Department of Energy and Mines, Mineral Resources Division, p. 70–83.

Theyer, P. 1985: Platinum-palladium distribution in ultramafic rocks of the Bird River complex, southeastern Manitoba; Manitoba Energy and Mines, Geological Services, Open File Report 85-4, 46 p.

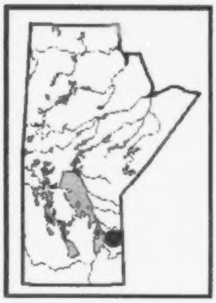
Theyer, P. 2001: Platinum group elements in Manitoba – progress report for 2001 (abstract); Manitoba Industry, Trade and Mines, Manitoba Mining and Minerals Convention 2001, November 15–17, 2001, Winnipeg, Manitoba, Program, p. 45.

Theyer, P. Bruni, E. and Sundell, C. 2001: Stratigraphy, geology and mineralization of selected parts of the Page property, Bird River Sill (part of NTS 52L/5); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 126–132.

Trueman, D.L. 1980: Stratigraphy, structure and metamorphic petrology of the Archean greenstone belt at Bird River, Manitoba; Ph.D. thesis, University of Manitoba, 150 p.

GS-29 PHYTOREMEDIATION OF MINE TAILINGS AND BIO-ORE PRODUCTION: PROGRESS REPORT ON SEED GERMINATION, SURVIVAL AND METAL UPTAKE OF SEEDLINGS PLANTED AT CENTRAL MANITOBA (AU) MINESITE (NTS 52L13)

by S. Renault[1], E. Sailerova[2] and M.A.F. Fedikow[3]



Renault, S., Sailerova, E. and Fedikow, M.A.F. 2002: Phytoremediation of mine tailings and bio-ore production: progress report on seed germination, survival and metal uptake of seedlings planted at Central Manitoba (Au) minesite (NTS 52L13); *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 255–265.

SUMMARY

A project was initiated in 2000 at the Central Manitoba (Au) minesite in southeastern Manitoba to determine the potential for revegetation, phytoremediation and phytomining of mine tailings through the identification of plant species that can avoid or tolerate the presence of heavy metals. Sixteen plant species, seedlings as well as seeds, were planted on three experimental sites of mine tailings and in the greenhouse on the tailings material. Results have shown that several plant species were able to survive for three growing seasons on two of the three selected sites without any additional treatment. Wheatgrass seeds demonstrated the highest survival rate in both greenhouse and in the field. Capping of tailings with peat on the third site allowed survival of some of the seedlings for at least two growing seasons. Laboratory results indicate a promising enrichment of metals in roots and in some shoots of selected plant species.

INTRODUCTION

Tailings are the waste product of ore processing operations and they can pollute the environment with significant quantities of heavy metals. At present, modern techniques avoid the uncontrolled release of tailings in the environment. However, there are many vast, exposed and untreated tailing sites that desperately need effective remediation and revegetation to avoid significant risk to the environment and to the health of people living in the area.

Most of the heavy metals are released from the tailings to the environment after being oxidized. The oxidation of the tailings in air under moist conditions results in lowering of the pH and leads to an increased solubility of the heavy metals. Metal mobilization from tailings can often be traced into watersheds downstream from active mining sites. Low pH, presence of metals in toxic quantities, the lack of vegetative cover and organic nutrients prevent seed germination and plant growth. Tailings thus form large and bare areas with no vegetation cover. This in combination with their often powdery nature makes them a source of enormous dust production. Affected soil cannot be used for agricultural purposes because of the high metal content and other land uses are limited. Today's practices of removing the contaminated soil (excavation) are very expensive (Giasson and Jaouich, 1998).

Oxidation of the tailings can be controlled by covering the surface with soil and then usually revegetating the site. Establishment of a self-sustaining mat of vegetation is usually an important element in a rehabilitation program for waste-disposal areas. Vegetation stabilizes the soil, prevents new acid-generating material from being exposed and decreases the amount of water available for deep percolation through transpirational water movement. Vegetation is established by controlling pH near the surface with the addition of lime or limestone and by adding peat and fertilizers where necessary. This treatment can increase initial plant survival rate and help to induce adaptation processes. Plant species are usually selected from well-adapted species growing in the region (Bradshaw, 1952). Nevertheless, revegetation alone does not stop acid drainage and does not necessarily remove heavy metals from the contaminated site.

Phytoremediation of soils contaminated with heavy metals is being developed as a potential cost-effective remediation solution for thousands of contaminated sites in the United States and abroad (Salt et al., 1995, 1998; Cunningham et al., 1995; Comis, 1996). Phytoremediation of tailings, however, is a problem that remains to be addressed on a case-specific basis. It might be necessary to revegetate with grass species before introducing the species that are the most effective in extracting metal from the tailings.

A relatively new approach to phytoremediation involves the introduction of highly tolerant species with high biomass production, capable of accumulating 0.5 to 1% of their dry weight in metals. The shoots of these plants are harvested at the end of the growing season and burned, forming a metal-rich bio-ore (Nicks and Chambers, 1998). The choice of hyperaccumulator species must also be climate and site specific, and sensitive to regulations restricting the

---

[1] Department of Botany, University of Manitoba, Winnipeg, Manitoba, R3T 2N2

[2] M.E.S.S. Consultants, 683 Borebank Street, Winnipeg, Manitoba, R3N 1G1

[3] Mount Morgan Resources Ltd., 34 Wellesley Court, Winnipeg, Manitoba, R3P 1X8

introduction of foreign species.

Phytomining technology offers the possibility of exploiting ores or mineralized soils that are uneconomic by conventional mining methods. Bio-ores are virtually sulphur free and their smelting requires less energy than sulphide ores. The metal content of a bio-ore is usually much greater than that of a conventional ore and therefore requires less storage space, despite lower density. Moreover, phytomining is an environmentally responsible approach to site remediation.

OBJECTIVES

The long-term goal of this study is to define limiting factors for phytoremediation of mine tailings and other sites contaminated with heavy metals. This study will establish the scientific basis for the remediation of mine tailings and extraction of heavy metals by phytomining techniques. Practical experience will be gained in the routine remediation of mine tailings and possibly in the extraction of heavy metals. Plant species selected for the study will include plants native to the surrounding environment and seeds of plants acclimated on-site will be also tested. The suitability of selected species for phytomining for base metals and gold will be tested in terms of the quality and costs of bio-ore production and economic effectiveness.

SIGNIFICANCE OF THE WORK

Soil contamination by heavy metals, and metal leakage and dust production from sulphide tailings represents a significant and widely recognized ecological hazard. Phytoremediation offers the possibility of an ecologically acceptable and cost-effective solution. Phytomining, a new technique for extracting metals from low-grade ore or sulphide tailings, is a promising technique currently being developed for commercialization in the United States. Field experiments in phytomining in Manitoba could provide valuable information regarding the potential of this method to remediate sites contaminated with heavy metals.

GEOLOGICAL SETTING OF THE CENTRAL MANITOBA (AU) DEPOSIT

Tailings associated with the Central Manitoba (Au) deposit were selected for initial phytoremediation and phytomining studies. A description of the geological setting of this deposit is detailed in Renault et al. (2000, 2001).

GEOCHEMICAL CHARACTERIZATION OF TAILINGS AND DESCRIPTION OF EXPERIMENTAL SITES

Three experimental sites were chosen based on the proximity to the tailings edge and vegetation cover, exposure to sun and wind, and drainage conditions (Sailerova, 2000). Site 1 was positioned relatively far from the tailings edge, partially sheltered by sporadic vegetation cover and poorly drained. Site 2 was located in the middle of the tailing mass with no vegetation cover, fully exposed to the wind and sun and well drained. Site 3 was located close to the tailings edge, relatively well sheltered and drained. The pH values were measured at all three experimental sites in 2002. At sites 1 and 2, pH values were in the range of 3.5 to 4 in oxidized zones and 6.5 to 7 in non-oxidized zones. At site 3, pH values ranged from 5 to 7.

Results of geochemical analyses of 20 tailings samples collected from three hand-augered profiles, approximately 1 m deep, were presented in Renault et al. (2000).

RESULTS

Greenhouse Study

Seeds of the following species were planted in the greenhouse: Indian mustard (*Brassica juncea*), white mustard (*Sinapis alba*), slender wheatgrass (*Agropyron trachycaulum*), altai wildrye (*Elymus angustus*), reed canary grass (*Phalaris arundinacea*), creeping foxtail (*Alopecurus arundinaceus*), streambank wheatgrass (*Agropyron riparium*) and tall fescue (*Festuca alatior*). Seeds were planted in trays on tailings collected from the top 15 cm of the three selected sites described above. Seeds of the selected species were also planted on tailings mixed with peat at a ratio of one to one and on a mixture of just peat and sand. The trays were sprayed with distilled water regularly to keep the moisture level relatively constant.

Indian mustard, white mustard and tall fescue seeds planted on tailings from sites 1 and 3 had the highest germination rates followed by slender wheatgrass and altai wildrye (Table GS-29-1). The remaining species (reed canary grass, creeping foxtail and streambank wheatgrass) had relatively low germination rates when planted in tailings from sites 1 and 3, as well as when planted in a mixture of peat and sand. This suggests that these species could just have low germination rates. Although Indian mustard and white mustard germinated well on tailings from sites 1 and 3, they were not able to survive for three months. Addition of peat to the tailings increased germination rates particularly at site 2 and greatly improved the survival rate of the seedlings at all sites (Table GS-29-1). This was in part a result of the increase in pH values. Among the grass species, tall fescue and reed canary grass are the species that produced the highest biomass when grown on site 1 amended with peat (Fig. GS-29-1). These species will be analyzed for metal content to determine their potential as reclamation or remediation species.

Experiments were designed in 2002 to test the efficiency of white mustard to absorb Cu in the presence of various chelators. These chelators will potentially enhance the plants' ability to absorb Cu from the tailings. Results will be available in 2003.

Table GS-29-1: Germination of seeds and survival of plants three months after seeding on tailings in the greenhouse.

	Peat with sand	Site 1	Site 2	Site 3	Site 1 (with peat)	Site 2 (with peat)	Site 3 (with peat)
Plant species							
				Germination (%)			
Indian mustard	100	88	0	88	96	34	96
White mustard	93	95	0	94	84	36	94
Altai wildrye	72	72	7	67	44	34	48
Slender wheatgrass	92	70	0	90	82	54	88
Reed canary grass	44	48	0	48	38	2	60
Creeping foxtail	40	56	0	52	54	4	62
Streambank wheatgrass	64	72	0	50	52	42	74
Tall fescue	88	80	0	86	82	18	76
				Survival (% of germinated seeds)			
Indian mustard	100	0	-	0	100	59	98
White mustard	100	0	-	0	100	50	100
Altai wildrye	100	93	0	69	100	100	100
Slender wheatgrass	100	89	-	41	85	96	98
Reed canary grass	100	42	-	83	89	0	93
Creeping foxtail	100	71	-	88	93	100	97
Streambank wheatgrass	100	94	-	92	96	90	95
Tall fescue	100	100	-	100	100	78	97

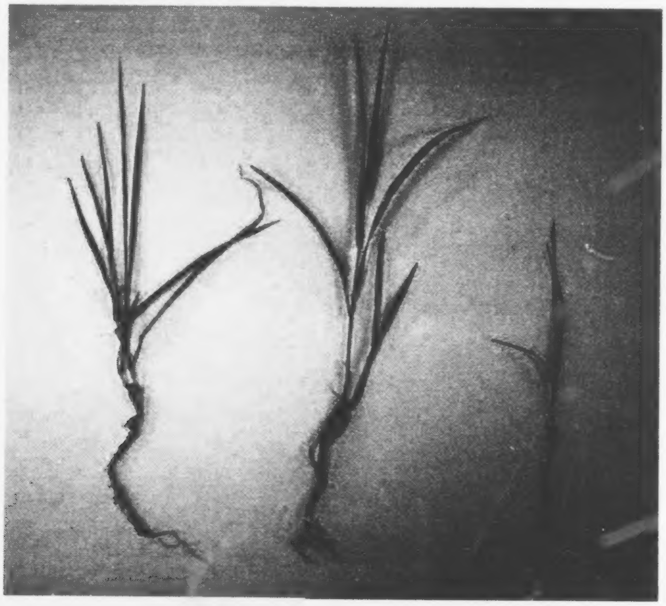


Figure GS-29-1: Reed canary grass grown on peat and sand (left), on site 1 tailings and peat (centre) and on site 3 tailings and peat (right).

Field Study: Plant Species Survival

In 2000, the following native tree species were planted on the three different sites: red-osier dogwood (*Cornus stolonifera*), yellow willow (*Salix lutea*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*), tamarack (*Larix laricina*) and bog birch (*Betula glandulosa*). In 2001, additional red-osier dogwood (*Cornus stolonifera*), yellow willow (*Salix lutea*), white spruce (*Picea glauca*) and jack pine (*Pinus banksiana*) seedlings were planted on the three sites. Prior to planting in 2001, a layer of peat (5 cm deep) was added on the top of the tailings on site 2. In 2002, additional red-osier dogwood seedlings were planted at sites 1, 2 and 3. Seeds of the following species were also planted (2001 and 2002) directly on tailings or after addition of peat at the three sites: Indian mustard (*Brassica juncea*), white mustard (*Sinapis alba*), slender wheatgrass (*Agropyron trachycaulum*), altai wildrye (*Elymus angustus*), reed canary grass (*Phalaris arundinacea*), creeping foxtail (*Alopecurus arundinaceus*), streambank wheatgrass (*Agropyron riparium*), tall fescue (*Festuca alatior*), tall wheatgrass (*Agropyron elongatum*) and Western wheatgrass (*Agropyron Smithii*).

Results showed that some tree seedlings were able to survive on sites 1 and 3. The tree seedlings rapidly died on the untreated, oxidized zones of site 2 (Table GS-29-2). However, in the areas of site 2 where peat had been added on the top of the tailings or mixed with the tailings matter, some seedlings were still alive after two growing seasons (Fig. GS-29-2, Table GS-29-2). Among the seedlings planted in 2000 at site 1, tamarack (Fig. GS-29-3) and white spruce had the highest survival rate followed by bog birch and jack pine. For the seedlings planted at site 1 in 2001, red-osier dogwood had the highest survival rate. For most seedlings, the survival rate was the highest when growing on site 3, likely due to the higher pH of the site (Table GS-29-2, Fig. GS-29-4, GS-29-5).

Table GS-29-2: Survival of seedlings planted on sites 1, 2 and 3. Measurements were taken in September 2002 after two and three growing seasons.

	Survival (%)		
Plant species (planted in 2000)	**Site 1**	**Site 2**	**Site 3**
Jack pine	50	0	83
White spruce	83	0	67
Tamarack	100	0	100
Red-osier dogwood	42	0	58
Yellow willow	30	0	69
Bog birch	75	0	100
Plant species (planted in 2001)	**Site 1**	**Site 2 (with peat)**	**Site 3**
Jack pine	45	5	94
White spruce	63	0	100
Red-osier dogwood	83	10	90
Yellow willow	38	13	92

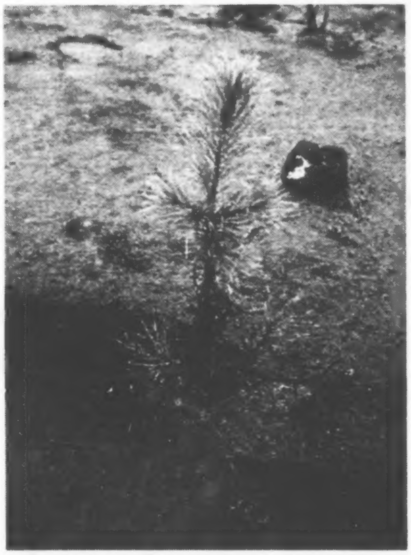


Figure GS-29-2: Jack pine on site 2 amended with peat after two growing seasons.

Figure GS-29-3: Tamarack on site 1 after three growing seasons.

Figure GS-29-4: Seedlings planted in 2001 on site 3.

Figure GS-29-5: Yellow willow planted in 2000 on site 3.

Indian mustard and white mustard seeds survived in the field when peat was added on the top of the tailings (Table GS-29-3). This is an important finding in light of the suitability of these species for phytoremediation and phytomining. Although biomass production was reduced when seedlings were grown on tailings, the addition of fertilizer to improve growth should be tested. Grass species planted in the spring of 2002 exhibited relatively high germination and survival rates; the highest survival rate was recorded for the wheatgrass species (western wheatgrass, slender wheatgrass, tall wheatgrass and streambank wheatgrass), followed by tall fescue and altai wildrye (Table GS-29-3). The difference in survival rate between seeds planted on an oxidized area of site 2 (pH 3.6) and seeds planted in a non-oxidized area of the same site (pH 7) was drastic (Table GS-29-3). The preliminary results showed that survival rate and the biomass of several plants were much higher in the non-oxidized area (Fig. GS-29-6). This result suggests that oxidation of the tailings, accompanied by a decrease in pH, seriously limits revegetation. However, this result will need to be confirmed by additional studies. The addition of limestone to increase the pH of the tailings at sites 1 and 3 is planned for the next growing season.

Overall survival rates were lower in the field than in the controlled conditions of the greenhouse, suggesting that monitoring of the plant growth at the beginning may be required to ensure successful re-establishment of vegetation on tailings.

Table GS-29-3: Survival of plants three months after seeding on sites 1, 2 and 3 in 2002.

Plant species	**Survival (% of planted seeds)**						
	Site 1	**Site 2**	**Site 3**	**Site 1 (with peat)**	**Site 2 oxidized (with peat)**	**Site 2 non-oxidized (with peat)**	**Site 3 (with peat)**
Indian mustard	0	0	0	25	8	n.a.	49
White mustard	0	0	0	49	6	n.a.	65
Altai wildrye	26	0	16	22	8	85	36
Slender wheatgrass	44	0	38	30	1	80	25
Reed canary grass	11	0	27	7	1	n.a.	11
Creeping foxtail	0	0	21	0	2	n.a.	3
Streambank wheatgrass	29	0	47	59	11	45	50
Tall fescue	35	0	50	7	10	n.a.	30
Tall wheatgrass	24	0	33	28	19	70	29
Western wheatgrass	50	0	38	37	28	n.a.	52

Note: n.a. - not available

Figure GS-29-6: Planting sites on oxidized (top of photo) and non-oxidized (bottom of photo) zones of site 2.

Elemental Analysis of Plant Tissues

In September 2001, seedlings planted in the field in 2000 (tamarack, white spruce, jack pine, dogwood, willow and birch) and some plants growing naturally on site [white spruce, horsetail (*Equisetum sp.)* and a grass species, Kentucky bluegrass (*Poa pratensis)*] were harvested, washed carefully and freeze-dried prior to elemental analysis. White mustard and Indian mustard, planted in the field and in the greenhouse on tailings amended with peat, were also analyzed for elemental analysis. The results of the analysis showed that plants growing on site 1 had a relatively high level of B (over 100 ppm in tamarack needles and willow shoots) compared to what is normally found in plants, which is 10 to 20 ppm (Table GS-29-4). Although boron is an essential element for plant growth, high levels can cause toxicity to the plant (Dudley, 1994). The level of Cu was elevated in all of the field samples tested (Table GS-29-4). Some plants are able to tolerate a relatively high level of Cu (Jones, Jr., 1998). Further experiments are needed to investigate the extent of Cu accumulation in the selected plants and test their potential role in removal of Cu from the tailings. This removal of Cu from tailings would enable the growth of species that are less tolerant to Cu. Levels of Al, V, Cr, Fe, As and Se were relatively high in the mustard species and some conifers compared to the other planted species (Table GS-29-4). Levels of Cd and Co were also relatively high in willow, dogwood and tamarack, while Ag levels were high in Indian mustard and jack pine (Table GS-29-4). The levels of Na and Mn were within the normal range for plants. On the other hand, the levels of macronutrients such as Mg, Ca and K in the tree species were generally lower than the normal range, suggesting that mineral deficiency might be a limiting factor for plant growth in the tailings. The level of Au in dogwood and willow roots was significantly higher than in the other plant species. No significant Accumulation of gold was found in the mustard shoots (Table GS-29-4), probably due to the small biomass produced. Further work will focus on enhancing the growth rate of the mustard species to determine the potential of these species for phytomining.

Table GS-29-4: Elemental analysis of plant shoots, roots, stems and needles harvested from the field (sites 1, 2 and 3) and from the greenhouse. All values are in ppm, unless otherwise noted.

Samples	Pre-ash wt (g)	Ash wt (g)	Ash (%)	B	Na (%)	Mg (%)	Al	K (%)	Ca (%)	V
Tamarack[1]										
Root - site 1	0.99 ± 0.02	0.13 ± 0.06	13.49	31.0 ± 28.8	0.04 ± 0.01	0.10 ± 0.04	309 ± 7	0.26 ± 0.04	1.92 ± 0.82	0
Stem - site 1	0.98 ± 0.03	0.03 ± 0.01	3.06	14.0 ± 2.0	0.02 ± 0.01	0.08 ± 0.02	70 ± 6	0.23 ± 0.03	0.44 ± 0.02	3.67 ± 0.58
Needles - site 1	0.89 ± 0.09	0.06 ± 0.01	6.82	290 ± 167	0.03 ± 0.01	0.18 ± 0.06	40 ± 5	0.68 ± 0.10	0.67 ± 0.09	6 ± 1
Root - site 3	1.00 ± 0.01	0.04 ± 0.01	4.01	9.3 ± 2.3	0.01 ± 0.01	0.06 ± 0.01	117 ± 43	0.27 ± 0.06	0.69 ± 0.10	7.33 ±1.16
Stem - site 3	1.00 ± 0.01	0.02 ± 0.01	2	8.3 ± 0.6	0.01 ± 0.01	0.06 ± 0.01	137 ± 79	0.20 ± 0.02	0.41 ± 0.03	7 ± 0
Needles - site 3	0.78 ± 0.05	0.04 ± 0.01	4.88	18.3 ± 4.5	0.02 ± 0.01	0.12 ± 0.03	73 ± 13	0.46 ± 0.06	0.80 ± 0.27	9 ± 1
White spruce[1]										
Root - site 1	0.99	0.07	7.31	17	0.015	0.076	288	0.155	1.57	11
Shoot - site 1	1.00 ± 0.01	0.03 ± 0.09	2.89	32.3 ± 29.3	0.02 ± 0.01	0.10 ± 0.03	74 ± 14	0.25 ± 0.14	0.38 ± 0.06	0
Root - site 3	1	0.06	6.09	11	0.039	0.156	429	0.281	1.5	0
Shoot - site 3	1.00 ± 0.01	0.03 ± 0.01	3.41	10.0 ± 2.0	0.02 ± 0.01	0.12 ± 0.04	162 ± 96	0.29 ± 0.07	0.55 ± 0.12	0
Jack pine[1]										
Root - site 1	0.66 ± 0.18	0.04 ± 0.02	6.22	21.7 ± 8.4	0.03 ± 0.02	0.09 ± 0.01	193 ± 64	0.43 ± 0.06	1.03 ± 0.29	0
Shoot - site 1	0.99 ± 0.01	0.03 ± 0.03	2.73	36.0 ± 13.5	0.02 ± 0.01	0.13 ± 0.02	129 ± 9	0.35 ± 0.03	0.37 ± 0.15	0
Root - site 3	1.00 ± 0.01	0.03 ± 0.01	3	7.7 ± 1.2	0.02 ± 0.01	0.07 ± 0.03	136 ± 68	0.41 ± 0.08	0.58 ± 0.15	3 ± 0
Shoot - site 3	1.00 ± 0.01	0.02 ± 0.01	2.3	10.0 ± 1.7	0.02 ± 0.01	0.09 ± 0.03	128 ± 18	0.23 ± 0.02	0.47 ± 0.07	0
Red-osier dogwood[1]										
Root - site 1	0.94 ± 0.12	0.03 ± 0.01	3.1	49.0 ± 14.1	0.02 ± 0.01	0.20 ± 0.05	136 ± 26	0.44 ± 0.03	0.52 ± 0.04	0
Shoot - site 1	0.74 ± 0.18	0.03 ± 0.01	4.71	55.7 ± 14.6	0.02 ± 0.01	0.08 ± 0.01	42 ± 8	0.26 ± 0.02	0.91 ± 0.04	0
Root - site 3	1.00 ± 0.01	0.03 ± 0.01	3.2	12.0 ± 0.0	0.02 ± 0.01	0.15 ± 0.04	99 ± 21	0.33 ± 0.07	0.56 ± 0.07	0
Shoot - site 3	0.98 ± 0.03	0.04 ± 0.01	3.96	27.0 ± 3.6	0.02 ± 0.01	0.08 ± 0.02	47 ± 18	0.24 ± 0.04	1.06 ± 0.21	0
Bob birch[1]										
Root - site 1	1.00 ± 0.01	0.03 ± 0.01	2.91	21.0 ± 7.0	0.02 ± 0.01	0.10 ± 0.01	57 ± 27	0.24 ± 0.04	0.61 ± 0.11	0
Shoot - site 1	1.00 ± 0.01	0.03 ± 0.01	3.5	29.0 ± 8.9	0.02 ± 0.01	0.09 ± 0.01	74 ± 22	0.20 ± 0.04	0.88 ± 0.13	0
Root - site 3	0.94 ± 0.07	0.05 ± 0.02	4.89	8.0 ± 1.0	0.02 ± 0.01	0.08 ± 0.01	90 ± 34	0.22 ± 0.04	0.88 ± 0.24	0
Shoot - site 3	0.91 ± 0.13	0.04 ± 0.01	3.97	19.3 ± 10.3	0.03 ± 0.01	0.10 ± 0.05	61 ± 22	0.27 ± 0.15	1.21 ± 0.30	0
Normal range in plants				10 to 20	0.02 to 0.5	0.2 to 0.3	10 to 200	0.5 to 1	0.5 to 1	0.5

[1] seedlings planted in 2000 in the field and harvested after two growing seasons, [2] seedlings growing on tailings, [3] seedlings harvested in the field, 4 seedlings harvested in the greenhouse

Table GS-29-4: Elemental analysis of plant shoots, roots, stems and needles harvested from the field (sites 1, 2 and 3) and from the greenhouse. All values are in ppm, unless otherwise noted. (continued)

Samples	Cr	Mn	Fe (%)	Co	Cu	As	Se	Au (ppb)	Ag	Cd
Tamarack[1]										
Root - site 1	23.3 ± 2.1	28 ± 15	0.06 ± 0.02	11.9 ± 7.4	1135 ± 524	1.7 ± 2.3	2.0 ± 4.6	13.8 ± 18.6	5.6 ± 5.5	1.4 ± 0.3
Stem - site 1	23.3 ± 2.1	83 ± 19	0.02 ± 0.01	0.6 ± 0.1	147 ± 54	2.6 ± 0.2	13 ± 1	14.7 ± 9.5	0.4 ± 0.1	0.3 ± 0.1
Needles - site 1	36.7 ± 3.8	224 ± 17	0.02 ± 0.01	1.3 ± 0.9	37 ± 25	6.3 ± 2.6	23.7 ± 1.2	12.8 ± 4.6	0.7 ± 0.1	0.1
Root - site 3	45.7 ± 9.3	26 ± 13	0.03 ± 0.01	1.0 ± 0.9	719 ± 678	6.1 ± 1.3	32.7 ± 7.6	7.2 ± 1.7	0.4 ± 0.1	0.8 ± 0.5
Stem - site 3	44.7 ± 1.5	56 ± 16	0.03 ± 0.01	0.4 ± 0.1	103 ± 24	5.7 ± 0.3	30.3 ± 2.1	8.2 ± 0.9	0.4 ± 0.1	0.2 ± 0.1
Needles - site 3	56 ± 6.2	166 ± 86	0.02 ± 0.01	0.2 ± 0.1	35 ± 23	7.2 ± 0.7	38 ± 2.6	7.4 ± 0.4	0.6 ± 0.1	0.1
White spruce[1]										
Root - site 1	67	39	0.027	2.1	732	8.2	42	22	1.7	0.3
Shoot - site 1	0	50 ± 41	0.03 ± 0.01	0.5 ± 0.1	122 ± 15	0	0	10.3 ± 3.0	0.4 ± 0.1	0.1
Root - site 3	4	20	0.076	1.2	2.17	1.2	8	10.2	0.8	0.8
Shoot - site 3	4 ± 1.7	48 ± 18	0.06 ± 0.03	0.6 ± 0.2	99 ± 15	0	0	4.2 ± 0.8	0.5 ± 0.1	0.1
Jack pine[1]										
Root - site 1	8 ± 12.5	15 ± 10	0.06 ± 0.04	2.8 ± 1.4	915 ± 302	0.5 ± 2.2	4.3 ± 9	36.2 ± 24.6	5.5 ± 4.3	0.6 ± 0.1
Shoot - site 1	15.3 ± 3.5	37 ± 12	0.05 ± 0.01	0.8 ± 0.4	194 ± 82	1.4 ± 0.4	8.7 ± 2.1	20.1 ± 5.6	0.5 ± 0.1	0.1
Root - site 3	21.7 ± 1.2	12 ± 3	0.03 ± 0.01	0.9 ± 0.3	1722 ± 681	1.8 ± 0.3	12 ± 1.7	9.0 ± 3.0	0.3 ± 0.1	0.6 ± 0.3
Shoot - site 3	14.7 ± 6.1	36 ± 17	0.04 ± 0.01	0.4 ± 0.1	78 ± 34	0.5 ± 1.1	4.3 ± 5.5	5.8 ± 0.9	0.3 ± 0.1	0.2 ± 0.1
Red-osier dogwood[1]										
Root - site 1	0	85 ± 11	0.02 ± 0.01	9.8 ± 2.8	1297 ± 595	0	0	206.3 ± 75.7	1.2 ± 0.1	1.8 ± 0.1
Shoot - site 1	0	11 ± 3	0.02 ± 0.01	0.4 ± 0.1	82 ± 3	0	0	6.4 ± 2.6	0.4 ± 0.2	0.1
Root - site 3	0	67 ± 13	0.02 ± 0.01	1.4 ± 0.6	824 ± 428	0	0	6.8 ± 6.0	0.5 ± 0.1	1.1 ± 0.4
Shoot - site 3	1.33 ± 2.89	12 ± 2	0.02 ± 0.01	0.2 ± 0.1	28 ± 7	0	0	2.4 ± 1.0	0.3 ± 0.1	0.1
Bob birch[1]										
Root - site 1	0	16 ± 5	0.02 ± 0.01	2.3 ± 0.5	257 ± 58	0	0	58.0 ± 10.8	0.3 ± 0.1	0.3 ± 0.1
Shoot - site 1	0	57 ± 31	0.03 ± 0.01	3.8 ± 1	103 ± 15	0	0	7.4 ± 2.9	0.2 ± 0.1	0.3 ± 0.1
Root - site 3	0	21 ± 9	0.03 ± 0.01	0.9 ± 0.4	528 ± 218	0	0	10.1 ± 7.4	0.3 ± 0.1	0.5 ± 0.3
Shoot - site 3	0	100 ± 56	0.02 ± 0.01	1.7 ± 0.8	52 ± 22	0	0	5.3 ± 7.5	0.3 ± 0.1	0.4 ± 0.2
Normal range in plants	1.5 to 2	10 to 200	0.01 to 0.02	0.5 to 3	6 to 40	1 to 2	0.02 to 5	1 to 5	0.2 to 2	0.1 to 1

[1] seedlings planted in 2000 in the field and harvested after two growing seasons, [2] seedlings growing on tailings, [3] seedlings harvested in the field, 4 seedlings harvested in the greenhouse

Table GS-29-4: Elemental analysis of plant shoots, roots, stems and needles harvested from the field (sites 1, 2 and 3) and from the greenhouse. All values are in ppm, unless otherwise noted. (continued)

Samples	Pre-ash wt (g)	Ash wt (g)	Ash (%)	B	Na (%)	Mg (%)	Al	K (%)	Ca (%)	V
Yellow willow[1]										
Root - site 1	0.51 ± 0.11	0.02 ± 0.01	3.95	21.7 ± 5.0	0.04 ± 0.01	0.12 ± 0.04	87 ± 24	0.45 ± 0.13	0.87 ± 0.06	0
Shoot - site 1	0.55 ± 0.06	0.02 ± 0.01	4.02	120 ± 42	0.04 ± 0.01	0.18 ± 0.04	65 ± 23	0.41 ± 0.11	1.83 ± 0.27	0
White spruce[2]										
Root - site 1	0.91 ± 0.16	0.02 ± 0.01	2.54	21 ± 14	0.02 ± 0.01	0.06 ± 0.03	87 ± 9	0.33 ± 0.05	0.58 ± 0.13	0
Shoot - site 1	1.00 ± 0.01	0.05 ± 0.01	4.79	61 ± 42	0.02 ± 0.01	0.09 ± 0.08	141 ± 58	0.40 ± 0.07	4.39 ± 5.72	0
Horsetail[2]										
Root - near site 3	0.58 ± 0.22	0.06 ± 0.04	10.5	26.3 ± 2.5	0.20 ± 0.02	0.20 ± 0.03	284 ± 76	1.48 ± 0.16	1.24 ± 0.24	0
Shoot - near site 3	0.93 ± 0.12	0.16 ± 0.03	17.28	31.3 ± 4.5	0.13 ± 0.02	0.20 ± 0.04	130 ± 45	2.07	1.69 ± 0.16	0
Kentucky blue grass[2]										
Shoot - site 2	0.91 ± 0.14	0.06 ± 0.01	6.13	6.3 ± 1.2	0.04 ± 0.01	0.30 ± 0.06	158 ± 113	1.15 ± 0.07	0.32 ± 0.14	0
White mustard[3]										
Root - site 3 with peat	0.15 ± 0.01	0.01 ± 0.01	9.03	18 ± 1.7	0.11 ± 0.02	0.18 ± 0.02	488 ± 42	2.84 ± 0.21	1.43 ± 0.12	0
Shoot - site 3 with peat	0.75 ± 0.09	0.12 ± 0.01	15.25	22.7 ± 0.6	0.07 ± 0.01	0.41 ± 0.03	511 ± 55	2.39 ± 0.15	2.86 ± 0.15	0
Indian mustard[3]										
Root - site 3 with peat	0.13 ± 0.02	0.01 ± 0.01	7.94	19.3 ± 0.6	0.11 ± 0.01	0.19 ± 0.02	741 ± 115	2.08 ± 0.06	1.73 ± 0.06	24.67 ± 1.16
Shoot - site 3 with peat	0.79 ± 0.12	0.08 ± 0.02	10.33	27.7 ± 0.6	0.03 ± 0.01	0.31 ± 0.01	224 ± 27	1.39 ± 0.04	2.56 ± 0.05	4.33 ± 0.58
White mustard[4]										
Shoot - site 1 with peat	0.60 ± 0.17	0.08 ± 0.01	12.67	83 ± 15 6	0.42 ± 0.05	0.43 ± 0.02	28 ± 8	2.3 ± 0.25	2.86 ± 0.38	7.33 ± 4.16
Shoot - site 3 with peat	0.62 ± 0.26	0.08 ± 0.03	12.42	21.3 ± 1.2	0.37 ± 0.06	0.31 ± 0.03	23 ± 9	2.17 ± 0.25	2.10 ± 0.29	0
Indian mustard[4]										
Shoot - site 1 with peat	0.59 ± 0.18	0.06 ± 0.02	9.88	43.7 ± 2.5	0.12 ± 0.01	0.25 ± 0.02	16 ± 3	2.16 ± 0.11	2.04 ± 0.15	0
Shoot - site 3 with peat	0.46 ± 0.19	0.06 ± 0.02	11.93	27 ± 1	0.13 ± 0.01	0.29 ± 0.01	18 ± 5	2.44 ± 0.12	2.05 ± 0.14	0
Normal range in plants				10 to 20	0.02 to 0.5	0.2 to 0.3	10 to 200	0.5 to 1	0.5 to 1	0.5

---

[1] seedlings planted in 2000 in the field and harvested after two growing seasons, [2] seedlings growing on tailings, [3] seedlings harvested in the field, 4 seedlings harvested in the greenhouse

Table GS-29-4: Elemental analysis of plant shoots, roots, stems and needles harvested from the field (sites 1, 2 and 3) and from the greenhouse. All values are in ppm, unless otherwise noted. (continued)

Samples	Cr	Mn	Fe (%)	Co	Cu	As	Se	Au (ppb)	Ag	Cd
Yellow willow[1]										
Root - site 1	0	35 ± 8	0.06 ± 0.07	7.9 ± 5.8	473 ± 282	0	0	211 ± 170.9	0.8 ± 0.2	1.7 ± 0.7
Shoot - site 1	0	94 ± 37	0.03 ± 0.01	2.7 ± 0.6	152 ± 88	1.33 ± 0.587	0	16.4 ± 9.8	0.7 ± 0.1	1.7 ± 0.6
White spruce[2]										
Root - site 1	0	50 ± 34	0.03 ± 0.01	3.3 ± 1.9	664 ± 352	0	0	89.0 ± 22.6	1.9 ± 2.0	0.2 ± 0.1
Shoot - site 1	2 ± 3.6	87 ± 39	0.05 ± 0.02	1.4 ± 1.4	299 ± 183	0.47 ± 1.04	3.7 ± 1.2	29.5 ± 8.0	0.7 ± 0.1	0.2 ± 0.1
Horsetail[2]										
Root - near site 3	5.3 ± 8.9	62 ± 15	0.10 ± 0.03	5.6 ± 1.2	1010 ± 65	0.27 ± 2.00	2.3 ± 6.4	113 ± 16.5	0.6 ± 0.1	0.5 ± 0.1
Shoot - near site 3	9 ± 4.4	65 ± 4	0.05 ± 0.01	1.7 ± 0.3	88 ± 36	1.53 ± 0.61	6 ± 2	10.2 ± 5.6	0.3 ± 0.1	0.1
Kentucky blue grass[2]										
Shoot - site 2	13 ± 3	130 ± 12	0.06 ± 0.04	0.7 ± 0.4	120 ± 98	1.67 ± 0.35	6.3 ± 1.5	20.2 ± 11.9	0.4 ± 0.2	0.1
White mustard[3]										
Root - site 3 with peat	97 ± 13.4	30 ± 2	0.12 ± 0.01	1.1 ± 0.1	174 ± 15	10 ± 1.73	42 ± 7.9	39.7 ± 7.6	1.5 ± 0.3	0.4 ± 0.1
Shoot - site 3 with peat	33 ± 1.7	37 ± 3	0.14 ± 0.01	1.2 ± 0.1	139 ± 14	4.63 ± 0.55	20.3 ± 1.2	17.6 ± 9.1	0.5 ± 0.1	0.62 ± 0.10
Indian mustard[3]										
Root - site 3 with peat	206.3 ± 11.0	30 ± 3	0.17 ± 0.03	1.3 ± 0.2	197 ± 27	24.3 ± 3.5	97.3 ± 3.2	58 ± 5.3	3.4 ± 0.1	0.2 ± 0.1
Shoot - site 3 with peat	35.3 ± 3.8	17 ± 1	0.06 ± 0.01	0.5 ± 0.1	75± 8	4.7 ± 0.52	20.3 ± 2.1	8.2 ± 0.4	0.5 ± 0.1	0.3 ± 0.1
White mustard[4]										
Shoot - site 1 with peat	65.3 ± 36.1	39 ± 4	0.02 ± 0.01	0.8 ± 0.2	52 ± 12	9.33 ± 5.13	40 ± 21.6	9.8 ± 2.3	0.5 ± 0.1	0.4 ± 0.1
Shoot - site 3 with peat	35 ± 14	44 ± 22	0.02 ± 0.01	0.3 ± 0.1	34 ± 15	5.57 ± 1.91	31.3 ± 3.8	3.3 ± 2.4	0.5 ± 0.3	0.3 ± 0.1
Indian mustard[4]										
Shoot - site 1 with peat	24 ± 6.6	37 ± 7	0.02 ± 0.01	0.4 ± 0.1	29 ± 4	4.13 ± 0.81	28.3 ± 5.0	4.6 ± 1.2	0.6 ± 0.1	0.4 ± 0.1
Shoot - site 3 with peat	33.7 ± 13.1	36 ± 3	0.02 ± 0.01	0.2 ± 0.1	34 ± 8	5.67 ± 2.52	36.7 ± 14.3	1.8 ± 0.3	0.8 ± 0.3	0.3 ± 0.1
Normal range in plants	1.5 to 2	10 to 200	0.01 to 0.02	0.5 to 3	6 to 40	1 to 2	0.02 to 5	1 to 5	0.2 to 2	0.1 to 1

[1] seedlings planted in 2000 in the field and harvested after two growing seasons, [2] seedlings growing on tailings, [3] seedlings harvested in the field, 4 seedlings harvested in the greenhouse

FUTURE WORK

The focus of the field and greenhouse experiments in the coming growing season will be the determination of the best combination of different amendments to the tailings surface layer to increase the long-term survival rate of selected plant species. These amendments will include lime or limestone, to adjust the pH of the tailings, peat and humic substances. Revegetation of the tailings with selected grass species will be further investigated focusing on increasing the survival rate and biomass production and possibly identifying those species that accumulate metals effectively. The metal content in plants that survive three growing seasons will be measured to determine the most promising species for phytoremediation purposes. In addition, the Cu content of the plants that were treated with chelators will be determined. Copper is the most abundant heavy metal present in the studied tailings. The fast-growing native species, such as horsetail, willow, poplar and fireweed, will be studied for their ability to form a cost-effective bio-ore.

ACKNOWLEDGMENTS

The authors would like to thank J. Mustard, C. Nakata and S. Medill for greenhouse and fieldwork assistance.

REFERENCES

Bradshaw, A.D. 1952: Population of *Agrostis tenuis* resistant to lead and zinc poisoning; Nature, v. 169, p. 1068.

Comis, D. 1996: Green remediation: using plants to clean the soil; Journal of Soil and Water Conservation, v. 51 (3), p. 184–192.

Cunningham, C.D., Berti, W.R and Huang, J.W. 1995: Phytoremediation of contaminated soils; Trends in Biotechnology, v. 13, p. 393–397.

Dudley, L.M. 1994: Salinity in the soil environment; *in* Handbook of Plant and Crop Stress, M. Pessarakli (ed.), Marcel Dekker Inc., New York, p. 13–30.

Giasson, P and Jaouich, A. 1998: Phytorestoration of contaminated soils in Quebec; Vecteur-Environnement, v. 31 (4), p. 40–53.

Jones, Jr., J.B. 1998: Plant Nutrition Manual; CRC Press, New York, 149 p.

Nicks, L.J. and Chambers, M.F. 1998: A pioneering study of the potential of phytomining for nickel; *in* Plants That Hyperaccumulate Heavy Metals, Their Role in Phytoremediation, Microbiology, Archeology, Mineral Exploration and Phytomining, CAB International, New York, p. 313–325.

Renault, S., Sailerova, E. and Fedikow, M.A.F. 2000: Phytoremediation and phytomining in Manitoba: preliminary observation from an orientation survey at the Central Manitoba (Au) minesite (NTS 52L/13); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 179–188.

Renault, S., Sailerova, E. and Fedikow, M.A.F. 2001: Phytoremediation of mine tailings and bio-ore production: results from a study on plant survival at the Central Manitoba (Au) minesite (NTS 52L/13); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 138–149.

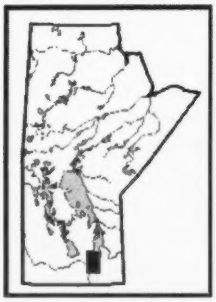
Sailerova, E. 2000: Geochemical flux in black spruce (*Picea mariana*) crowns and the correlation with root water uptake: effects of sample site drainage and tree crown morphology on crown twig and outer bark concentrations; Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Open File Report OF2000-4, 25 p.

Salt, D.E., Blaylock, M., Kumar, N.P.B.A., Dushenkov, V., Ensley, B.D. and Chet, I. 1995: Phytoremediation: a novel strategy for the removal of toxic metals from the environment using plants; Biotechnology, v. 13, p. 468–474.

Salt, D.E., Smith, R.D. and Raskin, I. 1998: Phytoremediation; Annual Reviews of Plant Physiology and Plant Molecular Biology, v. 49, p. 643–668.

GS-30 CAPITAL REGION STUDY (WINNIPEG AND SURROUNDING AREAS) UPDATE AND STRATIGRAPHIC DRILLING 2002, MANITOBA

by R.K. Bezys, J.D. Bamburak and G.G. Conley



Bezys, R.K., Bamburak, J.D. and Conley, G.G. 2002: Capital Region Study (Winnipeg and surrounding areas) update and stratigraphic drilling 2002, Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 266–272.

SUMMARY

The distribution of crushed stone resources in Manitoba's Capital Region area, primarily within formations of Ordovician age, have been determined from the examination of quarries, outcrops, water-well and corehole data. As a result of the compilation of this data, new depth to bedrock, bedrock topography, geology and mineral potential maps (1:50 000 scale) are being released in final format, accompanying a geological report (NTS map sheets 62H10, 11, 14 and 15 and 62I2, 3, 6 and 7). Six areas of high crushed stone potential were identified in and around the Capital Region. One site was identified within the City of Winnipeg, after the Manitoba Geological Survey drilled the prospective area. Contour mapping had determined that it was an area of shallow overburden thickness. All six areas should be protected from conflicting development and land sterilization.

INTRODUCTION

The City of Winnipeg is fortunate in having access to ample resources of carbonate bedrock immediately north of the city in the Rural Municipality of Rockwood (Fig. GS-30-1). The bedrock is composed primarily of calcium and magnesium carbonate and has many uses in today's economy such as crushed stone aggregates, cement, lime, chemical and metallurgical stone, fillers and extenders, building stone and pulverized stone. Manitoba's construction and transportation infrastructure rely heavily upon these resources and the limestone industry will remain a vital segment of the province's economy well into the future.

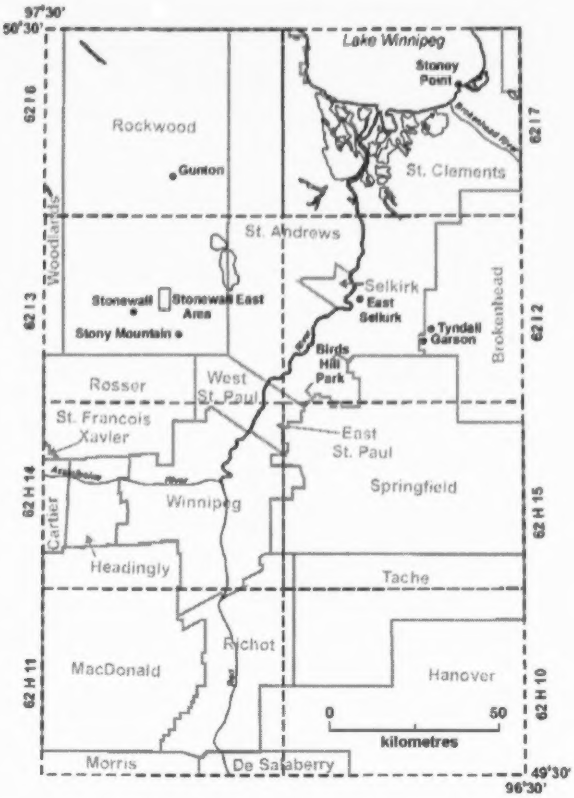

97°30'
50°30'
Lake Winnipeg
Stoney Point
Brokenhead River
62 I 6
62 I 7
Rockwood
Gunton
St. Clements
St. Andrews
Woodlands
Selkirk
East Selkirk
Stonewall
Stonewall East Area
Stony Mountain
Tyndall
Garson
Brokenhead
62 I 3
62 I 2
Birds Hill Park
Rosser
West St. Paul
St. Francois Xavier
East St. Paul
Springfield
Assiniboine River
Winnipeg
Cartier
Headingly
62 H 14
62 H 15
Tache
Ritchot
MacDonald
Red
Hanover
0
50
kilometres
62 H 11
62 H 10
Morris
De Salaberry
49°30'
96°30'

Figure GS-30-1: Capital Region Study area with rural municipality locations.

The Capital Region area (Winnipeg and surrounding municipalities) has exerted tremendous pressure on its resources in regard to land-use planning needs. In the Capital Region area, several localities, such as the towns of Stonewall and Stony Mountain (Fig. GS-30-1), possess areas of shallow bedrock exposures with high bedrock mineral potential. These sites have been, and continue to be, sources for crushed stone, primarily used in the City of Winnipeg.

Sand, gravel and crushed stone in the Capital Region are in high demand by the construction industry. Production of these commodities (including dimension stone) in the province was estimated at $44 million for 2001 (Table GS-30-1). This extraction forms the largest mining sector by volume produced and land acreage disturbed in Manitoba.

Historically, the population of rural Manitoba has been concentrated in urban centres, such as Winnipeg. However since the early 1970s, there has been a reverse migration from Winnipeg to outlying towns and municipalities. This movement has resulted in land-use patterns within these municipalities changing from rural agricultural to semi-urban and urban. This change has been accompanied by increased pressure by local residents and environmentalists to restrict quarrying of sand, gravel and crushed stone.

Housing subdivisions in the vicinity of active pits and quarries have been a source of public complaints. Quarrying is a heavy industrial land use, which can involve blasting, crushing, screening, operation of heavy equipment and local truck traffic, that may be disruptive to local residents. Rural municipalities within the Capital Region should discourage construction of dwellings in the vicinity of existing quarries or on near-surface bedrock with industrial mineral potential.

PREVIOUS WORK

The Capital Region Study (Fig. GS-30-1) consists of eight maps from the northern region (bedrock geology, bedrock topography, overburden thickness and mineral potential of NTS 62I2, 3, 6 and 7; at a scale of 1:50 000) and eight maps from the southern region (NTS 62H10, 11, 14 and 15; at a scale of 1:50 000). Preliminary, black and white versions of the first eight maps have been released (Bezys et al.,1999a–h). Colour versions of all maps accompany the final report, as well as extensive appendices with quarry descriptions.

The present Capital Region Study initially relied on previous work conducted by Bannatyne and Jones (1979) who produced geology, bedrock topography and overburden thickness maps for NTS 62I2, 3, 6 and 7 (1:50 000 scale). Mineral resource and engineering studies were carried out by Underwood McLellan and Associates Limited (1976) and Kjartanson (1983) for the Winnipeg area, and by James F. MacLaren Limited (1980) for the southern Interlake region. Jones (1986) studied the aggregate potential of bedrock exposures in the Capital Region. A geological and economic investigation was carried out by Bannatyne (1988) who examined the dolomite resources of southern Manitoba.

Table GS-30-1: Value of Manitoba stone and sand and gravel production, 1992–2001.[1]

Commodity	1992 ($000s)	1993 ($000s)	1994 ($000s)	1995 ($000s)	1996 ($000s)	1997 ($000s)	1998 ($000s)	1999 ($000s)	2000 ($000s)	2001 ($000s)
Sand and gravel	35,239	33,679	35,486	35,340	26,379	33,283	30,405*	29,989	26,968	26,855p
Stone									19,688	17,092p
limestone	6,243	8,318	10,170	13,058	11,315	15,487	16,675	15,614		
granite	1,510	2,597	1,775	1,851	2,993	3,106	8,196	4,376*		
shale	17	33	87	111	114	123	99	99		
Total	**43,009**	**44,627**	**47,518**	**50,360**	**40,801**	**51,999**	**55,375***	**50,078**	**46,656**	**43,947p**

Notes:

p = preliminary

* = estimated

[1] In Western Canada, the largest use of sand and gravel is for roadbed surfaces, followed by concrete aggregate, asphalt aggregate, and fill. However, production values shown in the table do not include shipments of stone and sand and gravel to Canadian cement and lime plants, but do include natural silica sand and crushed quartz or silica rock.

Source: Canadian Minerals Yearbook, 1992 to 1999 and http://www.nrcan.gc.ca/mms/ms-e.htm for 2000 and 2001.

METHODOLOGY

The rural municipalities of Rockwood, St. Andrews and St. Clements (Fig. GS-30-1) (NTS 62I2, 3, 6 and 7), in the northern part of the Capital Region, were selected as the first municipalities to be assessed and mapped because shallow bedrock was known to be present. To provide the required information in sufficient detail for land-use purposes, it was necessary to produce a computerized subsurface database consisting primarily of water-well records. These water-well records were used to map depth to bedrock, bedrock topography, bedrock geology and mineral potential. Water-well data was augmented with detailed examination of quarries, bedrock exposures and use of corehole information from the Manitoba Stratigraphic Database (MSD) (Bezys and Conley, 1999).

Geological mapping in the map sheet NTS 62I3 (containing the Rural Municipality of Rockwood) (Bezys et al., 1999c, d) (Fig. GS-30-1), using quarry inventories and water-well records, began in 1995. This map area was selected as the initial target for assessment because of the economically important crushed stone production in the Stonewall East and Stony Mountain areas.

Sixteen quarries were inventoried in the rural municipality of Rockwood in 1995 (Bamburak and Bezys, 1995). Data sheets for this project were modelled after Goudge (1944) and Derry Michener Booth and Wahl and Ontario Geological Survey (1989a–c). A stratigraphic section was generated for each quarry. The areal extent of each quarry was sketched and selected quarry sections were described, sampled and photographed. All field information was combined with historical descriptions, mineral inventory cards, property ownership maps and mineral disposition maps.

During the 1996 field season, the work was expanded to include the rural municipalities of St. Clements and St. Andrews. Data pertaining to the quarries were entered into a computer database; stratigraphic sections were drafted in final form; and industrial mineral inventory cards were updated (Bamburak and Bezys, 1996; Bezys et al., 1999a, b, g, h).

From 1995 to 1997, all water wells within the Capital Region Study area that intersected bedrock and had an accompanying survey location, were downloaded from GWDrill (Water Branch digital water-well database, Manitoba Conservation). This also included wells within river lots. Using the survey information, wells were plotted onto 1:50 000 scale topographic maps and UTM locations and ground elevations were corrected from a digital elevation model constructed from 1:20 000 contour and spot elevations. Infill data came from water wells whose locations were only accurate to the centre of the nearest legal subdivision (L.S.). This posed a problem because even in lightly populated areas, two or more wells were mapped to the same coordinate. The procedure used to select the infill well was to examine the stratigraphy of each water well at the location and then select the most appropriate ones based on the stratigraphic characteristics of the nearest neighbours. Stratigraphic wells from the Manitoba Stratigraphic Database were used as key reference points.

STRATIGRAPHIC DRILLING

A three corehole drilling program north of Stonewall was conducted by the Manitoba Geological Survey in 1996 (M-4-96, M-5-96 and M-6-96) (Bezys, 1996) and extended the aggregate resources of the Gunton Member of the Stony Mountain Formation 6 km to the northwest of a hole drilled in 1980 (M-1-80) (McCabe, 1980; Bannatyne, 1980). A subsequent three corehole drilling program in the Garson area (M-7-96, M-8-96 and M-9-96) (Bezys, 1996) confirmed the presence of additional dimension stone (Selkirk Member of the Red River Formation; Tyndall Stone™), 3 km to the southeast of the operating Gillis quarry.

In 1997, a three corehole drilling program near Selkirk was conducted as an extension of the sub-Phanerozoic, shield margin studies in NTS 62I2, and to investigate the Paleozoic and Precambrian geology of the Capital Region area (M-1-97, M-2-97 and M-3-97) (Bezys and Bamburak, 1997). Two of these holes intersected the Precambrian. In coreholes M-1-97 and M-3-97, thicknesses of the Selkirk Member, Red River Formation, ranged from 73.4 to 76.1 m. In corehole M-2-97, 15.5 m of undifferentiated Red River Formation was encountered and the hole had to be abandoned due to karst infill. All new corehole data were added to MSD.

2002 Stratigraphic Drilling and Results

To test the interpreted bedrock high (based upon the evaluation of water-well logs in GWDrill) in the vicinity of Sturgeon Road (in the northwest part of Winnipeg), two coreholes were drilled in 2002 (M-1-02 and M-2-02) (Fig. GS-30-2, GS-30-3, Table GS-30-2). The Sturgeon Road shallow bedrock area, mostly within the City of Winnipeg and partly in the Rural Municipality of Rosser, offers potential for crushed stone extraction, due to the presence of the highly sought after Gunton Member (Stony Mountain Formation). In corehole M-1-02, the overburden thickness is 4.5 m and the Gunton Member thickness is estimated to be 10.3 m, but due to the rubbly nature of the rock this

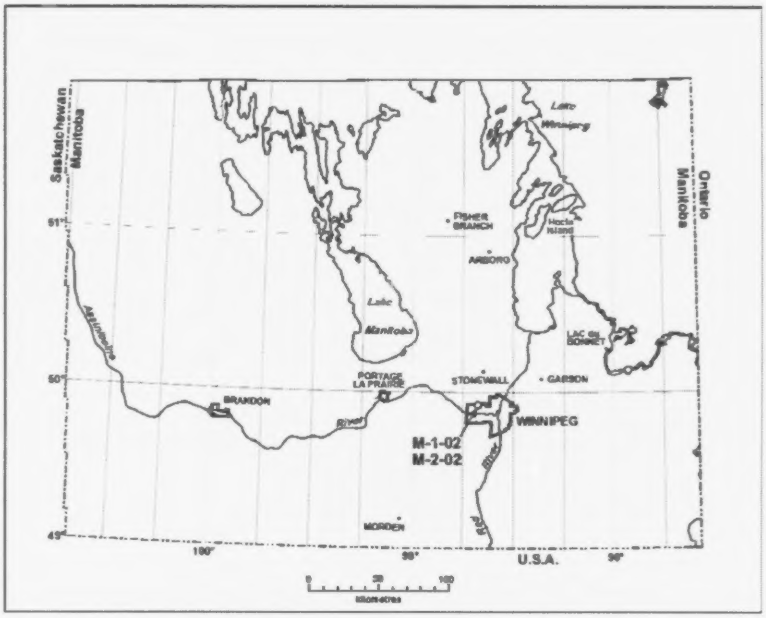

Saskatchewan
Manitoba
Ontario
Manitoba
Lake Winnipeg
Lake Manitoba
FISHER BRANCH
Hecla Island
ARBORG
Assiniboine
LAC du BONNET
PORTAGE LA PRAIRIE
STONEWALL
GARSON
BRANDON
River
WINNIPEG
M-1-02
M-2-02
Red River
MORDEN
51°
50°
49°
100°
98°
96°
U.S.A.
0
50
100
kilometres

Figure GS-30-2: Location of stratigraphic coreholes, 2002.

measurement is not exact. In corehole M-2-02, the overburden thickness is 3.5 m and the Gunton Member thickness is 5.9 m. With this thickness, the Gunton Member is extractable as a crushed stone resource. Bannatyne (1988), in his dolomite report, indicated an area of shallow bedrock (thin overburden) in west Winnipeg, and based on GWDrill water wells and MGS drilling (Fig. GS-30-3), this claim has been substantiated. To reduce haulage costs and overall costs to the City of Winnipeg, some resource extraction should be permitted.

CONCLUSIONS

Areas of thin overburden (< 5 m thick) are areas that should be protected for potential future extraction of crushed or building stone. These include the towns of Stonewall (and northeast of the town) and Stony Mountain; the town of Garson (and Tyndall); the town of Gunton; east of the town of East Selkirk; and the Sturgeon Road area, Winnipeg (Fig. GS-30-1, Table GS-30-3). The protection of these regions from future land-use pressure will ensure a supply of bedrock resources (either as crushed stone or building stone) for the Capital Region area. These resources provide a tremendous amount of wealth to the economy of Manitoba, and sterilization of these areas by land-use pressure will cause considerable expense as other alternative sources are sought.

ACKNOWLEDGMENTS

The authors would like to thank the many summer students who helped over the years to acquire the volumes of data required for this project. We thank C. Jones who initiated this idea, and we also thank G. Keller, B. Lenton, M. McFarlane and P. Lenton.

REFERENCES

Bannatyne, B.B. 1980: Dolomite resources of southern Manitoba; *in* Manitoba Department of Energy and Mines, Mineral Resources Division, Report of Field Activities 1980, p. 74.

Bannatyne, B.B. 1988: Dolomite resources of southern Manitoba; Manitoba Energy and Mines, Economic Geology Report ER85-1, 39 p. plus 4 maps at 1:50 000 scale.

Bannatyne, B.B. and Jones, C.W. 1979: Dolomite resources of the southern Interlake area; geology and bedrock topography; depth to bedrock; Manitoba Mines, Natural Resources and Environment, Mineral Resources Division, Preliminary Maps 1979DR-5 to DR-12 (NTS 62I/2, I/3, I/6 and I/7), scale 1:50 000.

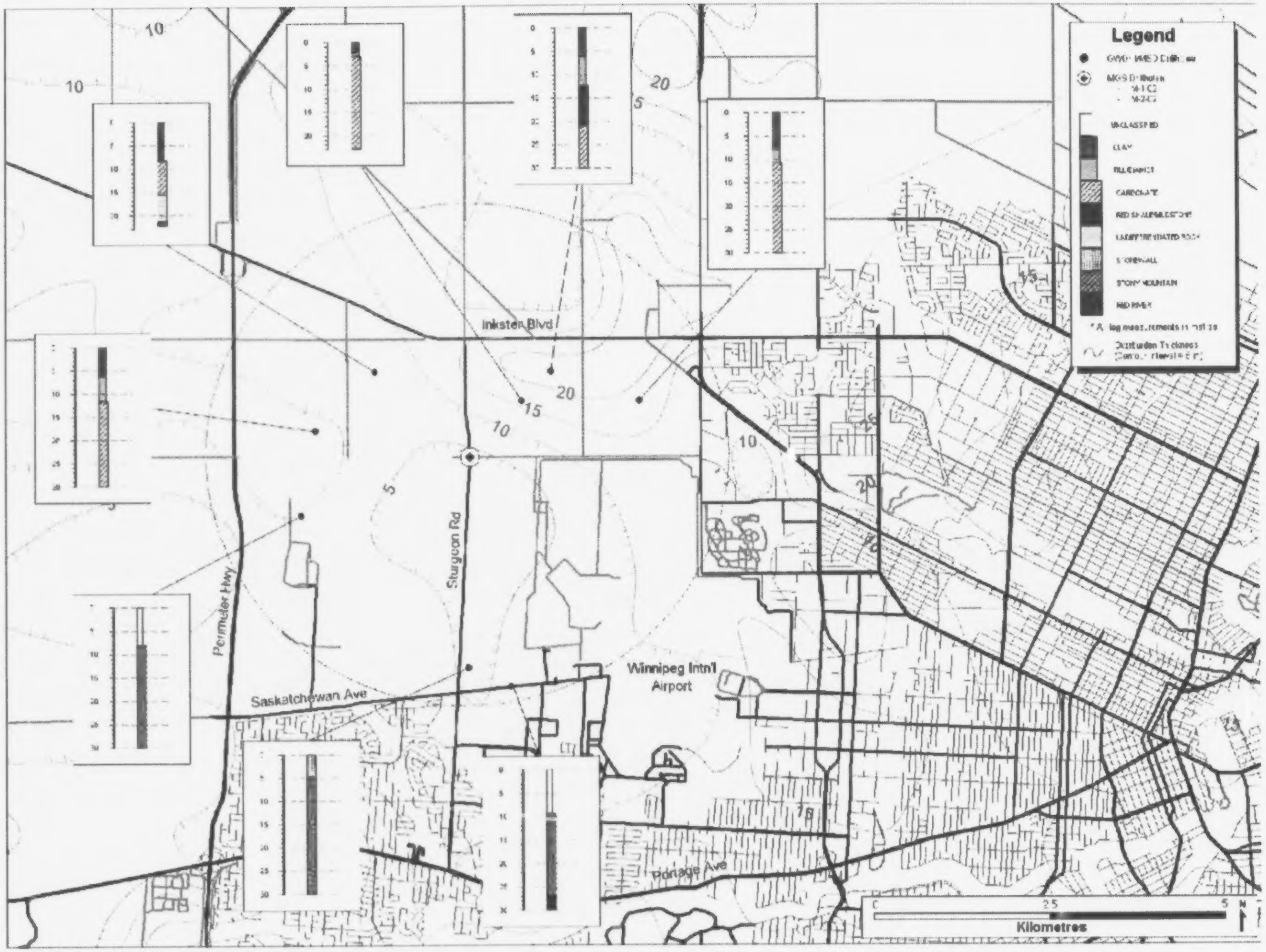

Legend
CLAY
CARBONATE
STONEWALL
STONY MOUNTAIN
RED RIVER
Inkster Blvd
Sturgeon Rd
Perimeter Hwy
Saskatchewan Ave
Winnipeg Intn'l
Airport
Portage Ave
0
2.5
5
Kilometres
N

Figure GS-30-3: Detailed location map of stratigraphic coreholes, 2002 and nearby water wells (with stratigraphic logs). See Table GS-30-2 for the 2002 corehole stratigraphic logs.

Table GS-30-2: Summary of stratigraphic corehole data, 2002.

Hole no.	Location and elevation (m)	SYSTEM/Formation/ (Member)	Interval (m)	Lithology summary
M-1-02	01-20-11-2-E1	OVERBURDEN	0.0–4.5	
Sturgeon Rd.	5532402N			
	623546E			
	240.5			
		ORDOVICIAN/Stony Mountain/(Gunton)	4.5–14.8	Tan dolomite, very rubbly
M-2-02	01-20-11-2-E1	OVERBURDEN	0.0–3.5	
Sturgeon Rd.	5532403N			
	623446E			
	240.5			
		ORDOVICIAN/Stony Mountain/(Gunton)	3.5–9.0	Mottled buff and yellow dolomite with pinpoint and vuggy porosity, rubbly in places, poor core
			9.0–9.4	As above, becoming bluish green downward, gradational into below
		(Penitentiary)	9.4–14.2	Mottled blue-green to grey dolomite, argillaceous, yellow in places, minor steel grey sulphides
		(Gunn)	14.2–31.0	Mottled grey, rounded clasts surrounded by red tendrils; limestone interbeds and calcareous shale (3–5 cm thick)
		Red River (Fort Garry)	31.0–32.6	Buff, very fine-grained dolomite

Table GS-30-3: Areas of high potential for crushed stone or building stone in the Capital Region.

Location	Formation (Member)
Town of Stonewall (and northeast of town)	Stony Mountain Fm. (Gunton Member)
Town of Stony Mountain	Stony Mountain Fm. (Gunton Member)
Town of Gunton	Stony Mountain Fm. (Gunton Member)
Town of Garson (and Tyndall)	Red River Fm. (Selkirk Member)
Town of East Selkirk (east of town)	Red River Fm. (Selkirk Member)
City of Winnipeg (Sturgeon Road)	Stony Mountain Fm. (Gunton Member)

Bamburak, J.D. and Bezys, R.K. 1995: Capital Region resource evaluation project (NTS 62I/3); *in* Manitoba Energy and Mines, Minerals Division, Report of Activities 1995, p. 151–154.

Bamburak, J.D. and Bezys, R.K. 1996: Capital Region study: update 1996 (NTS 62H and 62I); *in* Manitoba Energy and Mines, Minerals Division, Report of Activities 1996, p. 103–107.

Bezys, R.K. 1996: Stratigraphic mapping (NTS 63G) and corehole drilling program 1996; *in* Manitoba Energy and Mines, Minerals Division, Report of Activities 1996, p. 96–102.

Bezys, R.K. and Bamburak, J.D. 1997: Stratigraphic and industrial minerals corehole drilling program; *in* Manitoba Energy and Mines, Minerals Division, Report of Activities 1997, p. 123–128.

Bezys, R.K., Bamburak, J.D. and Conley, G.G. 1999a: Capital Region Study: mineral resource potential and overburden thickness, Selkirk (NTS 62I/2); Manitoba Energy and Mines, Geological Services, Preliminary Map 1999CAP-1, scale 1:50 000.

Bezys, R.K., Bamburak, J.D. and Conley, G.G. 1999b: Capital Region Study: geology and bedrock topography, Selkirk (NTS 62I/2); Manitoba Energy and Mines, Geological Services, Preliminary Map 1999CAP-2, scale 1:50 000.

Bezys, R.K., Bamburak, J.D. and Conley, G.G. 1999c: Capital Region Study: mineral resource potential and overburden thickness, Stonewall (NTS 62I/3); Manitoba Energy and Mines, Geological Services, Preliminary Map 1999CAP-3, scale 1:50 000.

Bezys, R.K., Bamburak, J.D. and Conley, G.G. 1999d: Capital Region Study: geology and bedrock topography, Stonewall (NTS 62I/3); Manitoba Energy and Mines, Geological Services, Preliminary Map 1999CAP-4, scale 1:50 000.

Bezys, R.K., Bamburak, J.D. and Conley, G.G. 1999e: Capital Region Study: mineral resource potential and overburden thickness, Teulon (NTS 62I/6); Manitoba Energy and Mines, Geological Services, Preliminary Map 1999CAP-5, scale 1:50 000.

Bezys, R.K., Bamburak, J.D. and Conley, G.G. 1999f: Capital Region Study: geology and bedrock topography, Teulon (NTS 62I/6); Manitoba Energy and Mines, Geological Services, Preliminary Map 1999CAP-6, scale 1:50 000.

Bezys, R.K., Bamburak, J.D. and Conley, G.G. 1999g: Capital Region Study: mineral resource potential and overburden thickness, Netley Marsh (NTS 62I/7); Manitoba Energy and Mines, Geological Services, Preliminary Map 1999CAP-7, scale 1:50 000.

Bezys, R.K., Bamburak, J.D. and Conley, G.G. 1999h: Capital Region Study: geology and bedrock topography, Netley Marsh (NTS 62I/7); Manitoba Energy and Mines, Geological Services, Preliminary Map 1999CAP-8, scale 1:50 000.

Bezys, R.K. and Conley, G.G. 1999: Manitoba Stratigraphic Database and the Manitoba Stratigraphic Map Series; Manitoba Energy and Mines, Geological Services, Open File Report OF98-7, 1 CD-ROM.

Derry Michener Booth and Wahl and Ontario Geological Survey 1989a: Limestone industries of Ontario, VolumeI – geology, properties and economics; Ontario Ministry of Natural Resources, Land Management Branch, 158 p.

Derry Michener Booth and Wahl and Ontario Geological Survey 1989b: Limestone industries of Ontario, Volume II – limestone industries and resources of eastern and northern Ontario; Ontario Ministry of Natural Resources, Land Management Branch, 196 p.

Derry Michener Booth and Wahl and Ontario Geological Survey 1989c: Limestone industries of Ontario, Volume III – limestone industries and resources of central and southwestern Ontario; Ontario Ministry of Natural Resources, Land Management Branch, 175 p.

Goudge, M.F. 1944: Limestones of Canada; their occurrence and characteristics: Part V, Western Canada; Bureau of Mines, Canada, Mines and Geology Branch, Report 811, 233 p.

James F. MacLaren Limited 1980: Mineral aggregate study of the southern Interlake region; Manitoba Department of Mines and Environmental Management, Mineral Resources Division, Open File Report OF80-2, v. 1 and 2, 51 p.

Jones, C.W. 1986: The aggregate potential of selected Paleozoic and Precambrian rocks in Manitoba; Manitoba Energy and Mines, Mines Branch, Aggregate Report 86-1, 13 p.

Kjartanson, B. 1983: Geological engineering report for urban development of Winnipeg; Department of Geological Engineering, University of Manitoba, Winnipeg, 78 p. plus 17 maps at 1:50 000 scale and 1 map at 1:30 000 scale.

McCabe, H.R. 1980: Stratigraphic mapping and core hole program, southwest Manitoba; *in* Manitoba Energy and Mines, Minerals Division, Report of Field Activities 1980, p. 70–73.

Underwood McLellan and Associates Limited (UMA) 1976: Aggregate resources of the Winnipeg region; Manitoba Department of Mines, Resources and Environmental Management, Open File Report OF77-4, 53 p.

GS-31 THE MANITOBA STRATIGRAPHIC DATABASE AND CAPITAL REGION STUDY: AN UPDATE

by G.G. Conley

Conley, G.G. 2002: The Manitoba Stratigraphic Database and Capital Region Study: an update; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 273.

SUMMARY

The Manitoba Stratigraphic Database continues to be updated with formation tops for 1663 wells added this summer to make a total of 3348 wells with formation tops, out of a total of 4713 wells.

The Capital Region Study report and final maps are being released in November 2002. New maps indicate near-surface bedrock, within and near the city of Winnipeg, that has high potential for the production of crushed stone aggregates.

MANITOBA STRATIGRAPHIC DATABASE: AN UPDATE

The Manitoba Stratigraphic Database continues to be updated. With the help of a Quebec exchange student, 1663 historical formation tops picked by H.R. McCabe (formerly of this department) were entered into the database. Combined with 1675 wells that were previously relogged and entered, this brings the total to 3348 wells with formation tops. The remaining 1365 wells still need to have formation tops entered. It is hoped that we will be able to acquire the assistance of another student in 2003 to complete the project. For more detailed information on both the Manitoba Stratigraphic Map Series and the Manitoba Stratigraphic Database, see Conley and Bezys (1998) and Bezys and Conley (1999).

THE CAPITAL REGION STUDY

The Capital Region Study has been completed and the report and final maps will be released in November 2002. The report consists of sixteen 1:50 000 scale map sheets, a report and several appendices. The appendices contain detailed quarry descriptions, quarry mineral inventory cards, section descriptions and quarry photographs. The report will be available in both digital and paper format. For more detailed information about the maps, please refer to Conley (2001).

The maps have indicated some new areas of near-surface bedrock close to and within the City of Winnipeg that have the potential for the production of crushed stone aggregates; aggregate similar to that currently being produced further to the north of the City, northeast of the Town of Stonewall. For further information see Bezys, Bamburak and Conley (GS-30, this volume; Bezys et al., in press).

ACKNOWLEDGMENTS

The author would like to acknowledge D. Lemaire of Quebec City, Quebec, for his assistance in entering such a large quantity of data this past summer.

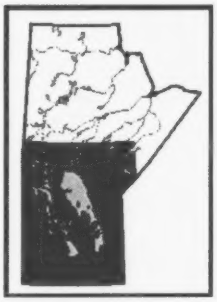
REFERENCES

Bezys, R.K., Bamburak, J.D. and Conley, G.G. in press: Bedrock mineral resources of Manitoba's capital region; Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Geoscientific Report GR2002-1.

Bezys, R.K. and Conley, G.G. 1999: Manitoba Stratigraphic Database and the Manitoba Stratigraphic Map Series; Manitoba Energy and Mines, Geological Services, Open File Report OF98-7, 1 CD-ROM.

Conley, G.G. 2001: Manitoba Stratigraphic Database and the Capital Region Study, 2001; *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 150–151.

Conley, G.G. and Bezys, R.K. 1998: The Manitoba Stratigraphic Map Series (Paleozoic and Mesozoic maps) and the Manitoba Stratigraphic Database: new and previously released subsurface geological data; *in* Report of Activities 1998, Manitoba Energy and Mines, Geological Services, p. 210–211.



GS-32 DEVELOPMENT OF METHODS FOR 3-D GEOLOGICAL MAPPING OF SOUTHERN MANITOBA PHANEROZOIC TERRANE

by G.L.D. Matile, G.R. Keller, D.M. Pyne[1] and L.H. Thorleifson[1]

Matile, G.L.D., Keller, G.R., Pyne, D.M. and Thorleifson, L.H. 2002: Development of methods for 3-D geological mapping of southern Manitoba Phanerozoic terrane; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 274-282.

SUMMARY

Three-dimensional (3-D) geological mapping of the Phanerozoic succession in southern Manitoba, south of latitude 55°N and west of longitude 95°W, is being completed as a successor activity to the Prairie component of the National Geoscience Mapping Program (NATMAP). The mapping is taking advantage of current developments in computer technology and is designed to support activity related to hydrocarbon, groundwater and industrial mineral development, for example. Much of the input data is in place, including topography, bathymetry, offshore geology, soil mapping, surficial geology, Quaternary stratigraphy, bedrock surface, bedrock geology, Phanerozoic stratigraphy and sub-Phanerozoic Precambrian geology. In addition, drillhole data crucial to the completion of a 3-D model for the Quaternary, as well as a revision of the Phanerozoic succession, have been compiled. The drillhole data compilation now links to water-well data held by the Water Branch of Manitoba Conservation, the Manitoba Stratigraphic Database (MSD), the Manitoba Oil and Gas Well Information System (MOGWIS) and newly digitized records held by the Manitoba Geological Survey. The Manitoba Geological Survey and the Geological Survey of Canada are carrying out development of the required 3-D protocols on a cooperative basis. Progress is being benchmarked with that of other Canadian, American and European geological survey organizations at international workshops in Illinois in 2001 and Denver in October 2002. These workshops are being sponsored by the Geological Survey of Canada and the Illinois State Geological Survey. The key activity during 2001 and 2002 has been the selection of computer hardware and software and the refinement of model construction, verification and communication procedures.

INTRODUCTION

The National Geoscience Mapping (NATMAP) program of the 1990s was established as a collaborative effort between Canada's federal and provincial governments, industry and the academic geoscience community to promote multidisciplinary, cooperative, geological mapping. Under the Prairie NATMAP project, new surficial geological mapping and Quaternary stratigraphic investigations were carried out in the Virden area of southwestern Manitoba and southeastern Saskatchewan (Blais-Stevens et al., 1999; Schreiner and Millard, 1995), as well as in the Winnipeg region of southeastern Manitoba. The Winnipeg project began in the early 1990s with mapping of an area south of latitude 50°N and east of longitude 97°W, an area equivalent in extent to one NTS 1:250 000 map sheet. Four preliminary surficial geology maps were produced for this area at a scale of 1:100 000. In the late 1990s, the Winnipeg study area was expanded to encompass the area south of latitude 51°N and east of longitude 98°W, the 200 km wide area south of Hecla Island and east of Portage la Prairie. The expanded study area was mapped as 12 surficial geology maps at a scale of 1:100 000, including the four maps from the first phase. These maps are in the final stages of production.

The objectives of the Winnipeg-area NATMAP and associated hydrogeology, Lake Winnipeg and Red River projects were to generate new, computer-based geological maps in order to better understand the geological features of the area. To enhance our ability to carry out geological investigations, NATMAP also made commitments to establish an infrastructure for the rapid production of digital maps and to train field geologists. Applications for the mapping include facilitation of mineral exploration, support for construction and other engineering activity, support for groundwater management, a better understanding of Lake Winnipeg shoreline erosion, as well as support for environmental and land-use management.

The NATMAP mapping in the expanded Winnipeg study area was extended into the subsurface with the aid of drillhole data and geophysical surveys, to develop a 3-D lithostratigraphic model for the Quaternary sediments (Matile et al., 1999b). Extension of the model to encompass the entire Phanerozoic succession was completed collaboratively with other programs of the Manitoba Geological Survey, including Phanerozoic stratigraphic investigations and the Capital Region Study (Bezys et al., GS-30, this volume). This pilot 3-D model for the Winnipeg region has been used to model groundwater flow across the region and to assess climate change scenarios with respect to impacts on groundwater systems (Kennedy, 2002).

Following completion of the Winnipeg area pilot model, a project to develop a 3-D stratigraphic model for the entire Phanerozoic terrane of southern Manitoba was launched (Matile et al., 2000, 2001). This study area encompasses most of the area south of latitude 55°N and east of longitude 102°W, a region over 400 km west to east and 600 km north to south. This paper reviews the progress in planning for and preliminary steps toward that model. First, the progress in the assembly of inputs, both data and partially processed modelling, is summarized. Then some of the issues raised by ongoing attempts to define potential protocols for final 3-D model construction, verification and communication are discussed.

---

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8

INPUTS TO THE MODEL

Assembly of the data and partially processed portions of the model that will be required for the southern Manitoba Phanerozoic model is nearing completion. These inputs include the following:

Topography

A 100 m grid cell digital elevation model (DEM) is being used as a datum for all data input to the model, including vertically positioning drillholes and the upper surface of the model. It has also been used for landform analysis and has drawn attention to previously unrecognized geological features. Data input for development of this model included rectification data for provincial digital orthophotography, federal 1:50 000 and 1:250 000 topographic maps and DEMs from neighbouring jurisdictions. Horizontal grid resolution for the DEM is 100 m and absolute vertical accuracy, is approximately ±3 m, based on an audit using primary vertical control. In September 2002, a version of the model, upgraded with new detailed data, was completed and prepared in grid format and high-resolution graphic files for web access (http://www.gov.mb.ca/itm/mrd/geo/demsm/introduction.html).

Bathymetry

To incorporate large lakes, including Lake Winnipeg, Lake Manitoba, Lake Winnipegosis, Playgreen Lake and Lake of the Woods in the 3-D model, 31 607 soundings on 22 Canadian Hydrographic Survey (CHS) charts were digitized and their locations were corrected relative to shorelines as depicted on NTS 1:250 000 topographic maps. The data were modelled at 100 m resolution after adjustment of the soundings from the varying CHS low-water datum to a consistent value for long-term mean lake level, and following addition of shorelines and shoals to the database.

Offshore Geology

During two cruises of the Canadian Coast Guard Ship *Namao* in 1994 and 1996 (Todd et al., 1998), low frequency and high frequency seismic data were acquired for over 1000 km of survey lines. The seismostratigraphy data was interpreted for the Quaternary sediments mapping and Paleozoic bedrock was differentiated from Precambrian on the basis of geometry and elevation. Where seismic velocities could be inferred, it was sometimes possible to distinguish till from Paleozoic bedrock. The offshore Quaternary and Paleozoic geology is now being modelled, guided by geology on land, bathymetry and seismic data digitized in the form of line-traces captured as profiles at intervals of five seconds of ship travel time.

Soil Mapping

Digital soil maps, produced by agricultural agencies, provide information on the texture and composition of sediment in the uppermost 0.5 m of the Quaternary sequence. Procedures to incorporate these data into the model are being assessed, such as the inclusion of an upper stratum that is much more detailed than the strata below.

Surficial Geology

A digital version of the surficial geology maps of southern Manitoba is being compiled at a scale of 1:250 000. A large part of this task is the conversion of data from paper maps to digital vector coverages. Map legends are being standardized and map polygon boundary discrepancies are being corrected. The map legend will define map units on the basis of factors such as texture, mineralogy, morphology and genesis of the sediments at depths between approximately 0.5 to 1.5 m. These maps guide the 3-D modelling, although at present the surficial mapping is more detailed than the resolution that can be achieved in the 3-D subsurface model. Consequently, the two models are not fully integrated, and as a result subsurface Quaternary strata outcrop as polygons that are generalized relative to the 1:250 000 mapping.

Quaternary Stratigraphy

The 3-D stratigraphic model of the Quaternary sediments in the Winnipeg pilot area was guided by an existing lithostratigraphic model based on previous research by Teller and Fenton (1980) and NATMAP project coring by Thorleifson and Matile (1993). The stratigraphic correlations, available from drillholes logged in detail, were extrapolated laterally with the aid of geophysical surveys, other drillhole data, topography and surficial geology mapping. A key source of data was the 80 000 site water-well database (GWDrill) which is maintained by the Manitoba Conservation Water Branch. Much effort was required to parse the 75 000 unique lithological descriptions in this database into geologically meaningful terms suitable for database operations. Additionally, it was necessary to assign locations at quarter section or river lot centroids, as well as elevations from the DEM, to locate the water wells in the database. For the NATMAP pilot, the 200 by 230 km area was divided into 46 transects, each 5 km wide, and a large colour cross-section chart was printed for each transect, showing all drillhole data, surficial geology and surface elevations. The drillhole data, colour-coded for lithology, were interpreted as a series of vertical maps using established techniques for lithostratigraphic correlation (e.g., Miall, 2000). Although the water-well data is variable in resolution and reliability, and rarely permitted the distinction of the units recognized at the stratigraphic reference sites, it did guide the interpolation between already correlated units and allowed the recognition of stark lithological breaks such as large sand lenses. To facilitate groundwater modelling, for example, it was necessary to predict the types of sediments present in areas of no data. The resulting west-east cross-sections were hand drawn as an overlay on the drillhole data, and the interpretation was captured as predicted stratigraphy points at 5 km intervals. The hand-drawn section approach, in which correlations were not linked to specific drillhole intersections, permitted the geologist to apply judgement by occasionally ignoring data based on suspect lithological descriptions or locations apparently in error. It is anticipated that the same methods will be used for the current study area, although plans are in place to experiment with an alternative approach in which the polygons drawn on the sections are digitized and linked to their lateral equivalents.

Bedrock Surface

Because the bedrock surface is being interpreted on all transects, a new bedrock elevation model will be produced as the new Quaternary model is compiled. As a result, the bedrock units need to be updated to accommodate the new bedrock surface model, while, at the same time, preserving the expert opinion incorporated into previously published bedrock maps.

Bedrock Geology

Model construction to date has been guided by Manitoba Geological Survey 1:1 000 000 bedrock geology map polygons, following linkage and reconciliation of conflicting versions of the polygons depicting outcrop and subcrop. A major effort was required to produce stacked polygons, in which each stratum is not truncated at the limits of overlying strata. Conversion of the model to reliance on 1:250 000 polygons is currently being assessed, as is revision of this mapping based on the drillhole compilation completed for the project. This compilation includes all available drillhole data, including Manitoba Stratigraphic Database (MSD), Manitoba Oil and Gas Well Information System (MOGWIS), Western Canada Sedimentary Basin Atlas database (WCSB), as well as newly digitized data previously stored on historical index cards.

Phanerozoic Stratigraphy

Stratigraphic maps with structure contours and isopachs of the Phanerozoic strata were previously compiled by the Manitoba Geological Survey (Bezys and Conley, 1999). The digital versions of these stratigraphic maps were obtained and supplemented where necessary with information from the Western Canada Sedimentary Basin Atlas (Mossop and Shetsen, 1994). A point dataset derived from the structural contours for each unit was gridded and trimmed to their extent as defined by the 1:1 000 000 mapping. The model has more units than were depicted in the Atlas, although less than are recognized in the Manitoba Stratigraphic Database, which includes many units that are only recognizable in limited areas. Modifications were required for pairs of previously modelled surfaces for which interpolations in data-poor areas were found to intersect. Whereas the current Phanerozoic model was derived directly from previously published stratigraphic maps, construction of a revised model is being contemplated, based on the drillhole compilation previously described. The water-well database also provides lithological data that can constrain the mapping. The drillhole data are now being plotted using methods similar to those previously described for the Quaternary. The current version of the pre-Quaternary model is being prepared for web release (http://www.gov.mb.ca/itm/mrd/geo/index.html). The site will permit users to query the model through a cross-section-based interface (Fig. GS-32-1), and display the full extent of the corresponding stratigraphic unit in map view. Users will also be able to rotate a 3-D block diagram for the Winnipeg NATMAP area and browse the geological model by progressively removing strata from a graphic model.

Sub-Phanerozoic Precambrian Geology

A preliminary sub-Phanerozoic Precambrian geology map for all of southern Manitoba was prepared in order to complete the model down to the deformed basement rocks. This map was compiled from aeromagnetic maps, compilation maps, drillhole and seismic data from Project Cormorant and subsurface correlation of drilled Precambrian intervals. A revision of the map is in progress.

WORKSHOPS

Implementation of the 3-D program has required choices to be made regarding hardware, software and protocols for construction, verification and communication of the 3-D model. In order to share ideas and benefit from experience recently gained by other agencies, the authors have participated in regular meetings sponsored by the Central Great Lakes Geological Mapping Coalition. After presenting posters and learning from the experience of others at Coalition-sponsored sessions in Illinois (Matile et al., 1999a) and Denver (Thorleifson et al., 1999), the authors collaborated with the Illinois State Geological Survey to sponsor two workshops on 3-D mapping and model development, one in Illinois in 2001 (Berg and Thorleifson, 2001) and the other in Denver in October 2002. Organization of and participation in the workshops have guided selection of options, and has indicated that, although approaches differ, the work being done in southern Manitoba is at a stage of development at least similar to corresponding activity elsewhere in North America and Europe.

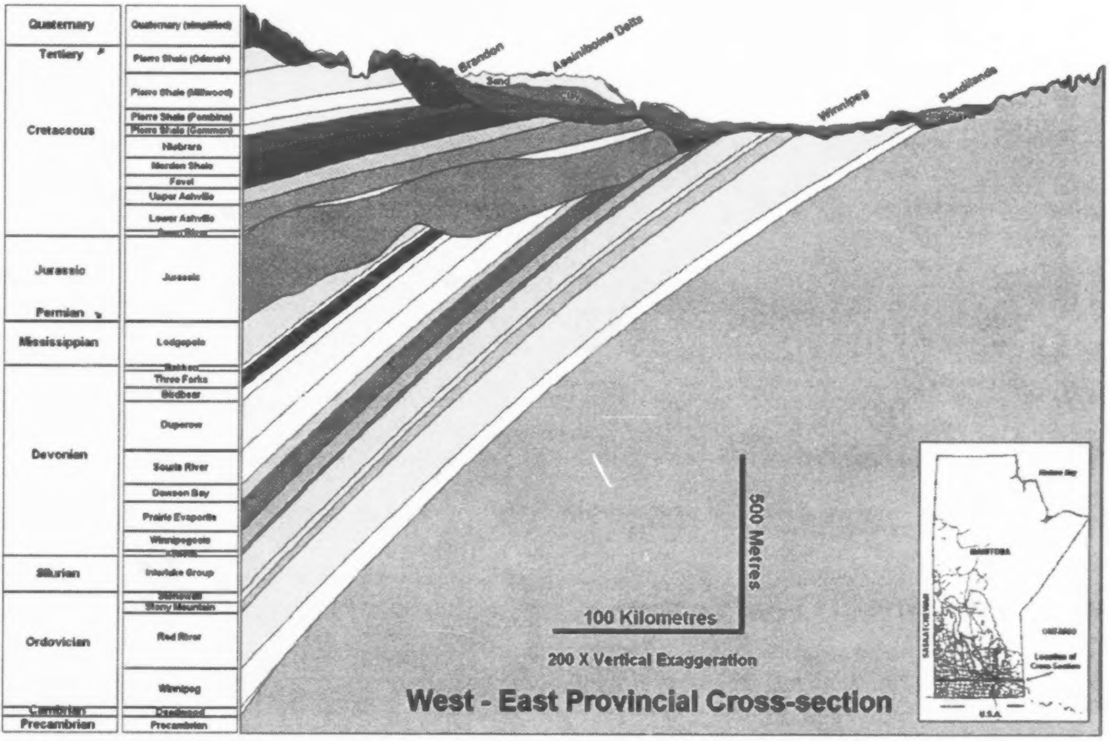

Quaternary
Tertiary
Cretaceous
Jurassic
Permian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
Precambrian
Quaternary (simplified)
Pierre Shale (Odanah)
Pierre Shale (Millwood)
Pierre Shale (Pembina)
Pierre Shale (Gammon)
Niobrara
Morden Shale
Favel
Upper Ashville
Lower Ashville
Swan River
Jurassic
Lodgepole
Bakken
Three Forks
Birdbear
Duperow
Souris River
Dawson Bay
Prairie Evaporite
Winnipegosis
Ashern
Interlake Group
Stonewall
Stony Mountain
Red River
Winnipeg
Deadwood
Precambrian
Brandon
Sand
Assiniboine Delta
Winnipeg
Sandilands
500 Metres
100 Kilometres
200 X Vertical Exaggeration
West - East Provincial Cross-section
Hudson Bay
MANITOBA
SASKATCHEWAN
ONTARIO
Location of Cross-Section
U.S.A.

Figure GS-32-1: West-east provincial cross-section through Winnipeg and Brandon depicting modelled Phanerozoic stratigraphy. Quaternary units have been simplified due to the limits of the vertical exaggeration.

MODELLING METHODS

The southern Manitoba Phanerozoic 3-D model envisaged here is intended to eventually supersede paper maps and their digital equivalents, so the methods that are being adopted are meant to conform to this objective. Traditionally, geological maps depict the extent of the uppermost stratum in the range of strata being mapped, while the legend, structural symbols and cross-sections convey superposition. Structural maps have shown the geometry of multiple strata by providing structure contours for the top of each stratum, which can be expressed as an isopach when one is subtracted from another. Structural charts typically have not, however, shown the elevation of the eroded edge of a stratum, the outcrop and subcrop, as this elevation is not relevant to interpreting the structural geology of the unit. This lack of elevation information for the eroded portion of a stratum is a limitation that requires correction before full 3-D modelling can proceed. Hence achievement of the objectives described here not only require selection of appropriate methods with reference to the software market and previous research (e.g., Shetsen and Mossop, 1994; Houlding, 1994), but also a more comprehensive definition of strata will be required. An adequate definition of a stratum will require the extent of the uneroded portion, elevation of its top, extent of its edge and elevation of its edge (Fig. GS-32-2).

A significant topic that is the subject of discussion and experimentation is the handling of contacts that together form map polygons. Contacts can either be input to the model or output from the model. In the case of the input approach, contacts on the Manitoba Geological Survey 1:1 000 000 and 1:250 000 geological maps are digitized as lines. The contacts would then be audited in plan view relative to recently obtained data, and would be revised. Wherever possible, the trend of these contacts would be maintained based on the assumption that the author would have drawn the contact as an expert prediction based on various considerations such as regional structure and lithology. In the case of bedrock contacts, it then would be necessary to have a complete model for the topography of the bedrock surface, so that the contacts could be converted from lines to points, and the model queried for elevation values for each point. Alternatively, the projection of the top of the stratum could be queried to obtain elevations for the upper contact, where the eroded edge meets the overlying stratum, and the lower contact could be positioned using the top of the underlying stratum. The lower contact is, of course, the upper contact of the underlying unit. Having audited and revised the contacts laterally, and having assigned them elevations, these lines would then be considered 'hard' inputs that have to be honoured by the model. Overlying and underlying surfaces would be forced to conform to these constraining lines.

The alternative to this approach is to allow the modelling procedure to generate new contacts based on a full 3-D analysis of all currently available data, including in some approaches, the previous geological models to guide the

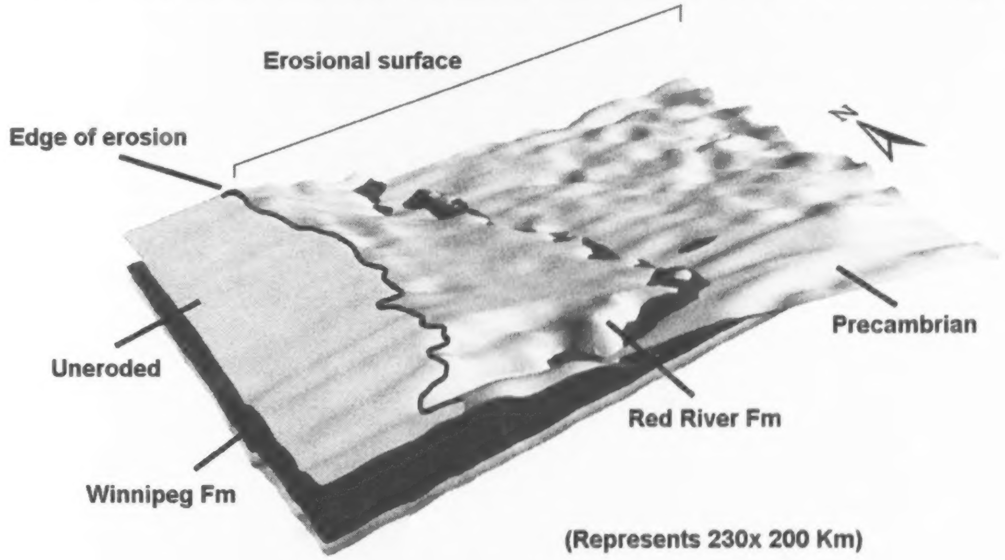


Figure GS-32-2: Each stratum is being defined by its full extent, the elevation of its uneroded top, as well as the extent and elevation of the edge that has been subject to erosion. The digital version also requires a surface defining the area of zero thickness that must coincide with the next lower surface that is present. In this example, the thickness of the Ordovician Winnipeg Formation in the area of exposed Precambrian is zero, so the top of the Ordovician Winnipeg Formation must equal the top of the Precambrian in this area.

interpretation. The advantage of this approach is that it honours more thoroughly, drillhole data obtained during the years since the maps were drawn, although there is a risk with this method that the expert opinion of the mapper may be lost if new interpolations are made. Having generated new upper and lower contacts for each unit, a new map polygon is created. It remains to be seen whether these new polygons would be accepted. Approaches will differ between Quaternary and pre-Quaternary due to the tendency of Quaternary units to feather out while many pre-Quaternary units terminate as escarpments. Furthermore, although the polygons guide 3-D model construction, the surficial geology map polygons are too detailed to be directly linked to the 3-D model, whereas all bedrock polygons will be linked to the 3-D units except for contacts that can only be mapped locally.

Modelling of the top elevation of each stratigraphic unit is being completed using an appropriate interpolation procedure, typically triangular irregular networks (TIN) base methods. A principal challenge is to avoid intersection of surfaces in data-poor areas. Methods for achieving this objective that are being tested include computer-based multiple-surface modelling procedures, database approaches to force the surfaces into order, and/or arithmetic approaches to remove intersections and impose a minimum thickness. Another issue in modelling surfaces is the choice of an appropriate compromise between strictly honouring data points and obtaining a slightly smoothed model that will aesthetically appear reasonable. Software has been found to vary significantly with respect to ease of interactively editing the grids that represent surfaces. Handling of discontinuous strata has also presented challenges, as some software options require that a new stratum be declared for each outlier. Over the past year, the 3-D software platform for the project has been converted to one capable of handling surfaces that represent the top of discontinuous strata.

In the case of the Winnipeg pilot, the 3-D model was conveyed as a series of surfaces modelled as TINs. There are advantages, however, in converting the intervals between the surfaces to solids, either hollow or filled, so the required computer infrastructure to do so is being implemented. Advantages include greater ability to interactively produce cross-sections with a pattern or colour filling each stratum, as well as an ability to assign properties to each solid, and to analyze it from the point of view of volume. It has been found, however, that constructing solids that do not 'leak' is a nontrivial exercise that requires selection among many options, as well as acceptance of unanticipated compromises such as simplification. Experiments completed for the project to date include hollow solids that produce linework cross-sections, as well as solids built as a matrix of tetrahedra. The matrix approach has some advantages but the tetrahedra solids are very large to store and slow to manipulate and give cross-sections with a corrugated effect. The currently favoured approach is the construction of a grid of vertical rectangular solids of varying thickness. The resulting solid is slow to manipulate in interactive applications but the computer technology to more readily handle the resulting solid model is likely to become readily available in forthcoming years.

Current procedures now allow a discontinuous stratum to be stored in the model as one unit with varying thickness. Where absent, however, the stratum must be specified as being present, but with a thickness of zero. This requirement has presented challenges. For example, a thickness of zero has to be specified for every Phanerozoic stratum at a Precambrian outcrop in eastern Manitoba. Because some smoothing and therefore slight deviation from data points are required for the surfaces to be aesthetically acceptable, successive zero thickness strata may not exactly coincide beyond the extent of the actual stratum where it has a non-zero thickness (Fig. GS-32-3). This would lead to a patchwork of fictitious thin outliers, some with negative thickness. This has been overcome by cutting out the area beyond the extent of a stratum from the next underlying continuous stratum, and stitching that surface to the less continuous stratum (Fig. GS-32-4). For example, the top of the Precambrian east of the extent of the Winnipeg Formation has been spliced to the top of the Winnipeg Formation where it is present, so the top of zero-thickness Winnipeg Formation east of its extent is exactly coincident with the top of Precambrian. A good 'seal' between the two surfaces is ensured if the top of the stratum beyond its extent is lowered in elevation prior to modelling (Fig. GS-32-5). The extent to which the zero thickness stratum needs to be pushed down in the area beyond its extent requires an iterative approach to achieve the desired result. Failure to seal individual surfaces results in thin tongues projecting beyond the actual extent of the stratum.

FUTURE PLANS

The assembly of inputs, both data and interim models, will be completed concurrently with iterative selection of modelling procedures. It is anticipated that this process will take several months and then a first version of the model can be released. The model will then serve as the basis for identifying priority areas for new data collection. Areas requiring upgrading will be identified using a confidence level based predominantly on data density and geological complexity and a priority level based on social and economic issues. The model then would be upgraded in increments indefinitely, with protocols in place for version identity and documentation. Concurrently with the refinement of models that define the outline geometry of units, progress will be required in defining the properties of the strata and

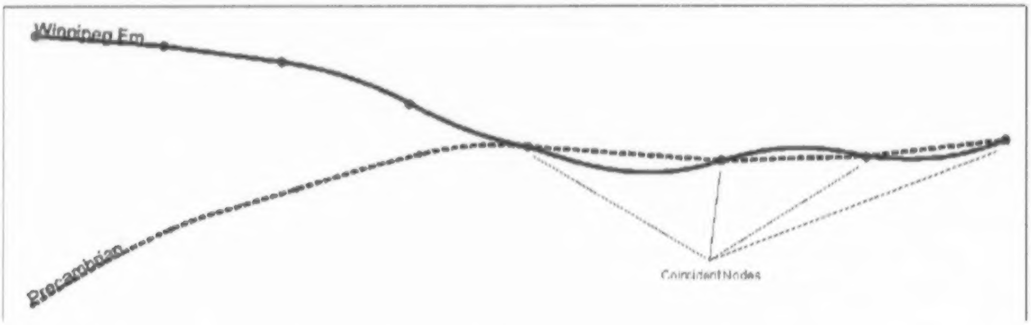

Winnipeg Fm
Precambrian
Coincident Nodes

Figure GS-32-3: Example of how two modelled surfaces of vertically adjacent units can deviate from one another even though they have coincident points beyond the extent of the upper unit.

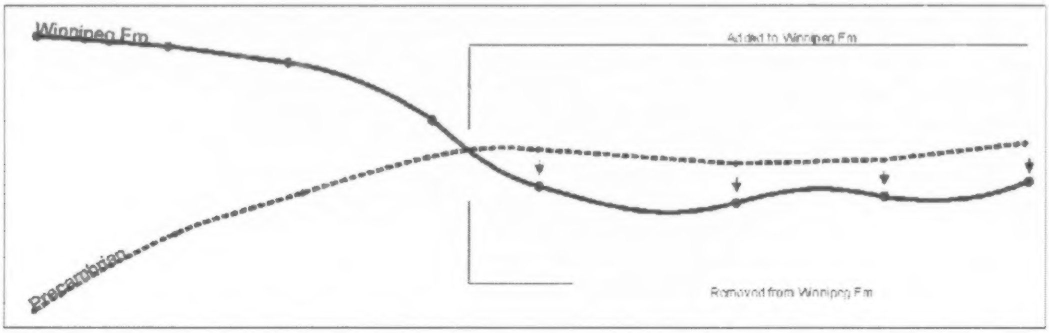

Winnipeg Fm
Added to Winnipeg Fm
Precambrian
Removed from Winnipeg Fm

Figure GS-32-4: Lowering the elevation of a stratum beyond its actual extent produces a surface that will seal against the underlying stratum, and also more realistically produces a limit that appropriately falls short of the first zero-thickness point.

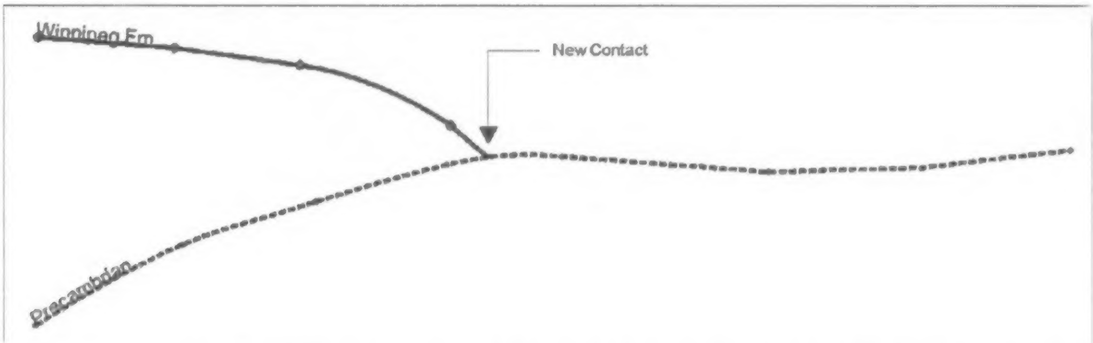

Winnipeg Fm
New Contact
Precambrian

Figure GS-32-5: The surface beyond the extent or surface intersection is removed and the surface of the next underlying stratum is spliced on, so the two are coincident where the thickness of the upper unit is zero.

their variability (e.g., Fraser and Davis, 1998). Finally, a major issue that is progressively being dealt with is the requirement to reconcile the model with corresponding activity in Saskatchewan, North Dakota, Minnesota and Ontario. Applications such as hydrocarbon and groundwater analyses in cross-border settings will fail if the respective models are not compatible. Achieving compatibility will require consultations, data sharing and compromise. When complete, the model will have many applications such as groundwater modelling, oil and gas assessments and industrial mineral management (Fig. GS-32-6).

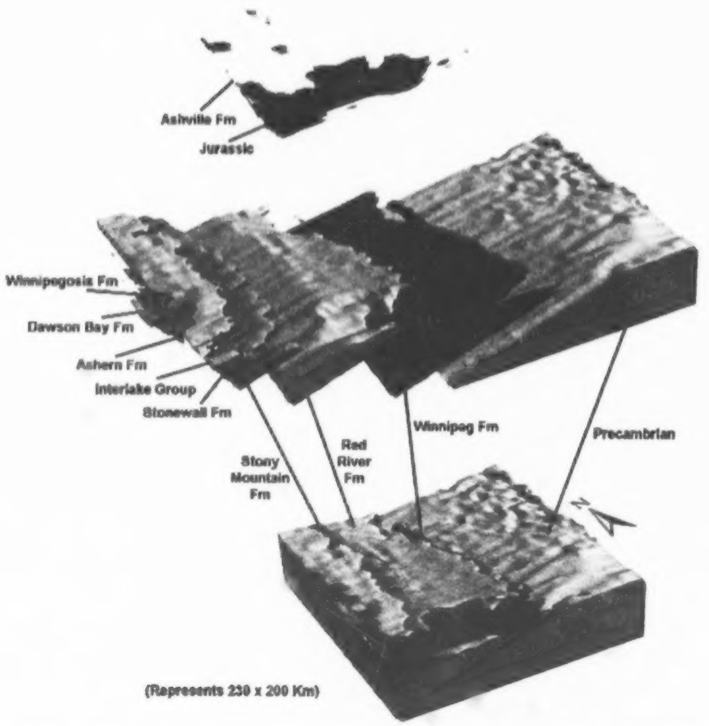


Figure GS-32-6: The 3-D model for the Phanerozoic geology of southern Manitoba will facilitate interactive viewing, as well as applications for groundwater modelling, oil and gas assessments and industrial mineral management.

REFERENCES

Berg, R.C. and Thorleifson, L.H. 2001: Geological models for groundwater flow modeling; Geological Society of America North-Central Section, Workshop Extended Abstracts, Illinois State Geological Survey, Open File Series 2001-1, 62 p.

Bezys, R.K. and Conley, G.G. 1999: Manitoba Stratigraphic Database and the Manitoba Stratigraphic Map Series; Manitoba Energy and Mines, Geological Services, Open File Report OF98-7, 1 CD-ROM.

Blais-Stevens, A., Sun, C. and Fulton, R.J. 1999: Surficial geology, Virden, Manitoba–Saskatchewan; Geological Survey of Canada, A-Series Map 1922A, scale 1:125 000.

Fraser, G.S. and Davis, J.M. 1998: Hydrogeologic models of sedimentary aquifers; SEPM Concepts in Hydrogeology and Environmental Geology, No. 2, 188 p.

Houlding, S.W. 1994: 3D Geoscience Modeling; Springer-Verlag, New York, 309 p.

Kennedy, P.L. 2002: Groundwater flow and transport model of the Red River/Interlake area in southern Manitoba; Ph.D. thesis, University of Manitoba, Winnipeg, 273 p.

Matile, G.L.D., Bamburak, J.D., Bezys, R.K., Conley, G.G., Burt, A.K., Grant, N.M., Mann, J.D., McDougall, W.J., Hughes, J.D. and Thorleifson, L.H. 1999a: New 3D geological mapping, Winnipeg region, Manitoba, Canada; Geological Society of America, North-Central Section, Champaign, Illinois, Abstracts with Programs, v. 31, no. 5, p. A-58.

Matile, G.L.D., Thorleifson, L.H., Grant, N., Burt, A. and Mann, J. 1999b: Geology of the Winnipeg region NATMAP Project (NTS 62H/W, 62I and 52L/W); *in* Report of Activities 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 114–115.

Matile, G.L.D., Thorleifson, L.H., Bamburak, J., Bezys, R., Burt, A., Conley, G., Grant, N., Keller, G., Mann, J., McGregor, C. and Pyne, M. 2000: Geology of the Winnipeg region NATMAP Project: 1999-2000 Progress (NTS 62H/W, 62I and 52L/W); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 189–193.

Matile, G.L.D., Thorleifson, L.H., Bamburak, J.D., Bezys, R.K., Nicolas, M.P.B., Conley, G.G., Keller, G.R. and Pyne, M. 2001: Construction of a 3D geological model for the southern Manitoba Phanerozoic terrane; *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 152–155.

Miall, A.D. 2000: Principles of Sedimentary Basin Analysis (3rd edition); Springer-Verlag, New York, 616 p.

Mossop, G.D. and Shetsen, I. (comp.) 1994: Geological Atlas of the Western Canada Sedimentary Basin; Canadian Society of Petroleum Geologists (Calgary) and Alberta Research Council, Edmonton, 510 p.

Schreiner, B.T. and Millard, M.J. 1995: Quaternary stratigraphic framework for the Virden area (62F); Saskatchewan Research Council, Publication R-1210-8-E-95, 18 p.

Shetsen, I. and Mossop, G.D. 1994: Automated data processing for the Geological Atlas of the Western Canada Sedimentary Basin; Chapter 35 *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists (Calgary) and Alberta Research Council, p. 503–507.

Teller, J.T. and Fenton, M.M. 1980: Late Wisconsinan glacial stratigraphy and history of southeastern Manitoba; Canadian Journal of Earth Sciences, v. 17, p. 19–35.

Thorleifson, L.H. and Matile, G.L.D. 1993: Till geochemical and indicator mineral reconnaissance of southeastern Manitoba; Geological Survey of Canada, Open File 2750, 1 diskette.

Thorleifson, L.H., Matile, G.L.D., Bamburak, J.D., Bezys, R.K., Conley, G.G., McDougall, W.J., Hughes, J.D., Burt, A.K., Grant, N.M. and Mann, J.D. 1999: New 3D geological mapping, Winnipeg region, Manitoba, Canada; Geological Society of America Annual Meeting, Denver, Abstracts with Programs, v. 31, no. 7, p. A-81.

Todd, B.J., Lewis, C.F.M., Nielsen, E., Thorleifson, L.H., Bezys, R.K. and Weber, W. 1998: Lake Winnipeg: geological setting and sediment seismostratigraphy; Journal of Paleolimnology, v. 19, p. 215–244.

GS-33 CONTRIBUTIONS OF DENDROCHRONOLOGY TO FLOOD HAZARD ANALYSIS IN THE RED RIVER BASIN, MANITOBA

by S. St. George[1] and E. Nielsen

St. George, S. and Nielsen, E. 2002: Contributions of dendrochronology to flood hazard analysis in the Red River basin, Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 283–286.

SUMMARY

Research conducted by the joint Manitoba Geological Survey–Geological Survey of Canada (MGS–GSC) dendrochronological laboratory in Winnipeg has provided baseline geoscientific data critical to the understanding of past hydroclimatic change in Manitoba and its impact on flood hazards in the Red River valley and local groundwater supplies. The current tree-ring record for the Red River basin extends back to AD 1286 and has been used to construct a flood history for the Red River at Winnipeg that spans the last 350 years. Since AD 1648, anatomical signatures in riparian trees document extreme floods in 1997, 1979, 1950, 1852, 1826, 1762 and 1747. This record implies that the risk of flooding changes over time and therefore, the risks of future flooding for Winnipeg and other communities in the Red River valley might be better estimated using techniques that account for non-stationairity and non-randomness introduced by climatic and landscape changes. Tree-ring estimates also suggest that while southern Manitoba's hydroclimate has been relatively stable over the last 200 years, conditions prior to permanent Euro-Canadian settlement were much more variable and persistent. Finally, statistical modelling suggests that, during the 20th century, hydraulic groundwater heads near Winnipeg had a greater range prior to the 1960s, most prominently during an interval of lowered groundwater levels between 1930 and 1942.

INTRODUCTION

In 1999, the Manitoba Geological Survey (MGS) and Geological Survey of Canada (GSC) established a joint dendrochronology laboratory at the MGS office in Winnipeg. This facility has supported ongoing research into past climatic change and its influence on natural hazards in Manitoba. Although researchers at the laboratory have been involved with a number of ancillary projects, particularly those related to archeological dating, work has focused mainly on providing baseline scientific data to better understand flood hazards for communities in the Red River valley. This report summarizes recent projects related to Red River flooding as well as long-term climatic variability and change in Manitoba and its impact on local groundwater resources.

DENDROCHRONOLOGY IN THE RED RIVER BASIN

Trees growing in temperate regions can provide a wide range of information related to past environmental change and extreme events, since the annual rhythm of tree growth represents an absolutely dated annual record that can span several hundred or even thousands of years. The current tree-ring network in southern Manitoba includes specimens collected from three main sources. Samples from living trees were collected at 16 sites inside a 100 km long riparian corridor following the Red River. Timbers were recovered from nearly a dozen historical buildings and Euro-Canadian archeological sites, the majority of which were located inside present-day Winnipeg. Lastly, subfossil logs were recovered from alluvial sections (between Emerson and Morris on the Red River and between Portage la Prairie and Winnipeg on the Assiniboine River) that were exposed during low water stages. The combined record for the Red River basin includes 398 crossdated trees and extends from AD 1286 to 1999 (St. George and Nielsen, 2002).

Flood Hazards in the Red River Valley

More than any other large city in Canada, Winnipeg has suffered repeated physical, social and economic injury due to severe flooding. Although Winnipeg largely escaped the "flood of the century" in 1997 without enduring serious damage, the Red River still forced the evacuation of over 28,000 people in Manitoba and had a direct economic impact of roughly $500 million. Similar large floods threatened Winnipeg in 1979 and 1950 and caused extensive damage to the fledgling Red River Settlement in 1861, 1852 and 1826.

Conventionally, the future risk of extreme floods is estimated from the occurrence of such floods in the past. The likelihood of future floods greater than those observed in the historical record is estimated by extrapolation. However, since instrumental flood records are often less than 100 years in length, extrapolated return intervals for large floods are highly uncertain. For example, the flood-frequency curve for the Red River in Winnipeg, originally derived in the 1960s, changed substantially when updated with additional years of data (Burn and Goel, 2001). Furthermore, the flood-frequency approach assumes that flood-generating processes do not change over time and that floods are random in time and space (Baker et al., 2002). These assumptions have been criticized as arbitrary and unrealistic (Klemeš, 1989), especially since flooding is a dynamic process that is often affected by geomorphological, geological and climatic change (Baker et al., 2002). Although these changes can occur very slowly, they may be very significant when considered over the time horizons used in the design of flood protection structures (typically between 100 to 1,000 years).

---

[1] Geological Survey of Canada, 360-1395 Ellice Avenue, Winnipeg, Manitoba, R3G 3P2

Estimates of flood risks in the Red River valley can be enhanced by using markers preserved in natural archives, such as trees and lake sediments, that were left by past extreme floods. Paleofloods are floods that occurred in the past that were not recorded by direct or indirect human observation (Baker et al., 2002). Paleoflood hydrology can greatly improve our understanding of local flood hazards by reducing the uncertainty in estimates of long return-period floods and by adding a historical component to flood hazard assessment (Baker et al., 2002). Extreme Red River floods (on the order of the 1950 flood or larger) cause bur oak (*Quercus macrocarpa* Michx.) growing along the river to develop distinctive anatomical markers (Fig. GS-33-1; St. George and Nielsen, 2000; St. George and Nielsen, in press) that can be used to identify older and previously unknown Red River floods.

Tree-ring evidence provides a record of flooding for the lower Red River basin (LRB), between Winnipeg and Morris, that extends from AD 1648 to 1999 (St. George and Nielsen, in press). During that period, anatomical signatures provide evidence for seven high-magnitude floods: 1997, 1979, 1950, 1852, 1826, 1762 and 1747. Although the five most recent flood rings are coincident with known high-magnitude floods, signatures in 1747 and 1762 predate local instrumental and historical flood records and represent previously unknown floods. Despite comments by an early fur trapper that suggests flooding was unusually extensive in 1776 (Ross, 1856), we find no tree-ring evidence for such an event. The flood signature record for the LRB contains three periods during which the Red River generated multiple high-magnitude floods: the mid 1700s, the mid 1800s and the latter half of the 20th century. Conversely, the record also indicates that the LRB experienced prolonged intervals with little to no extreme flooding, particularly between 1648 and 1746, 1763 and 1810, and 1862 and 1949. Tree-ring evidence also suggests that the Red River flood of 1826 was clearly exceptional and was the most severe flood that occurred in at least the last 352 years. Subfossil logs collected from river alluvium likely originated from upstream reaches in North Dakota and Minnesota and therefore document flood history in the upstream portion of the basin. Tree-ring records from alluvial oaks span the interval AD 1448 to 1997, and contain anatomical signatures for nine floods: 1762, 1747, 1741, 1727, 1726, 1682, 1658, 1538

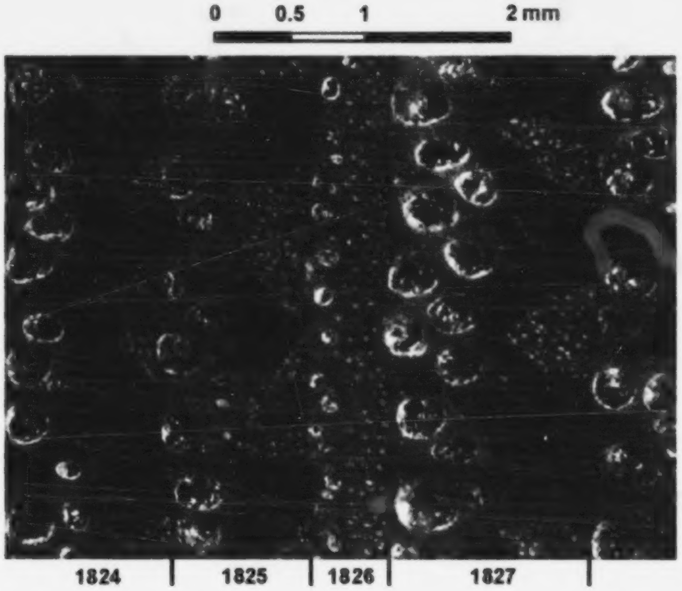


Figure GS-33-1: Flood signatures associated with Red River flooding are characterised by shrunken earlywood vessels. Several flood signatures for 1826 contain anatomical abnormalities, including disrupted latewood and flame parenchyma, that are not present in flood signatures for other years. From St. George and Nielsen (in press).

and 1510. However, since sample depth for the upper basin is relatively low (only five alluvial logs contain flood signatures), this dataset cannot estimate the relative magnitude for upper basin floods.

Flood frequency analysis is based on the assumption that the flood flows are independent and identically distributed random variables (National Research Council, 1999). However, these 'high' and 'low' flood modes in the Red River record, which have extended from several decades to nearly a century, imply that the risk of flooding changes over time. Statistical analysis of the instrumental and historical flood series for the Red River indicate that high flows over the last 200 years have been clustered (Booy and Morgan, 1985) and non-stationary (Burn and Goel, 2001). Therefore, the risks of future flooding for Winnipeg and other communities in the Red River valley might be better estimated using techniques that account for non-stationairity and non-randomness introduced by climatic and landscape changes.

Tree-ring data can also provide additional information about the mechanisms that have contributed to extreme floods in the past. For example, flood signatures present in oaks collected from the Assiniboine River suggest that the two basins, which have dramatically different hydroclimates, flooded simultaneously in 1510, 1538 and 1826. This evidence demonstrates that while synchronous floods are rare, they are certainly possible. The Assiniboine River and Red River floods in 1826 were also coincident with severe frost damage recorded at tree-ring sites across the south-central United States (Stahle, 1990), which implies that unusual spring weather extended throughout central North America.

Long-term Hydroclimatic Change in the Red River Basin

Although intuition suggests that extreme floods would be more common under a wetter climate, specific climatic thresholds leading to shifts in regional flood hazards are difficult to determine. Estimated annual (prior August to current July) precipitation derived from regional bur oak ringwidth indicates that southern Manitoba's hydroclimate has been relatively stable over the last 200 years (Fig. GS-33-2; St. George and Nielsen, 2002). Although this stability was interrupted briefly by pronounced wet intervals in the late 1820s and 1850s, hydroclimatic conditions since permanent Euro-Canadian settlement were much less variable and persistent than those prior to AD 1790. The reconstruction indicates that the Red River basin experienced extremely dry conditions between AD 1670 and 1775, with below normal precipitation occurring approximately two years out of three.

In the past, hydroclimatic change in southern Manitoba has occurred at two distinct temporal and spatial scales. Over the last 300 years, most individual dry years were associated with widespread drought across much of the North American interior. However, longer-term multi-decadal shifts in hydroclimate, such as the AD 1700 dry interval, appear

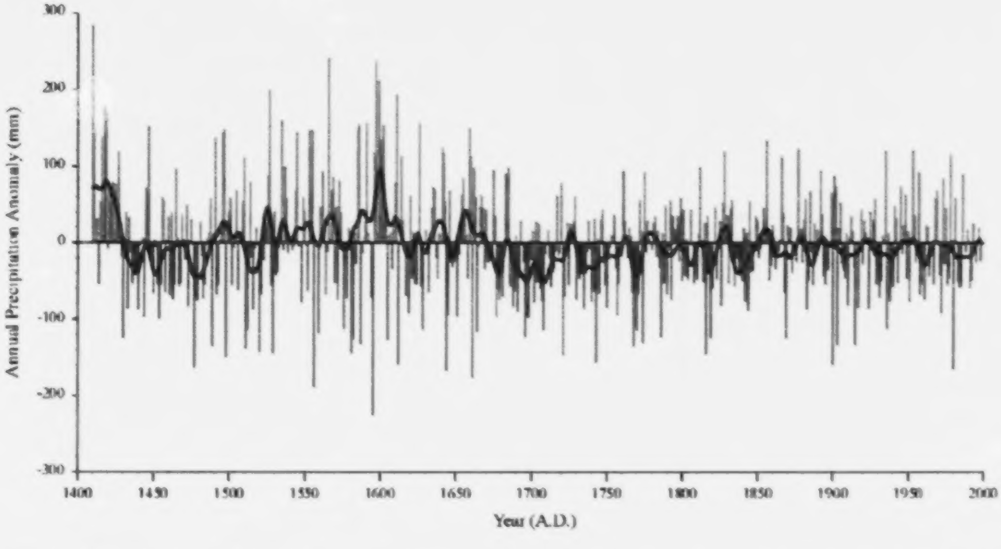


Figure GS-33-2: Reconstructed annual (August–July) precipitation at Winnipeg from AD 1409 to 1998. Units are mean annual precipitation deviations from 1961 to 1990. Black line represents 15-year weighted running mean. From St. George and Nielsen (2002).

to have been restricted to the northeastern Plains. As long-term hydroclimatic change seems to have operated independently of larger-scale droughts, it is possible that the mechanisms driving changes in regional aridity depend on the temporal and spatial scales under investigation. These paleoenvironmental records indicate that natural variation in this region can generate shifts in precipitation regimes that last for several decades and extend over several thousand square kilometres (St. George and Nielsen, 2002). As a consequence, it seems likely that climatic case studies in regional drought and flood planning based exclusively on experience during the 20th century may dramatically underestimate true worst-case scenarios. Past changes in regional precipitation on the order of roughly ten percent that occurred under 'natural climatic' conditions also appear to have exerted a significant influence on regional flood risks, at multi-decadal and centennial time scales.

Estimated Changes in Groundwater during the 20th Century

In Winnipeg, instrumental groundwater records begin in the early 1960s. These records are too short to identify decadal or multi-decadal trends within an aquifer and make it difficult to determine the long-term impact of climatic variation on groundwater usage. G. Ferguson and S. St. George (work in progress, 2002) used a suite of climatic and tree-ring data to estimate historic groundwater levels through most of the 20th century, prior to instrumental observation. This analysis indicates that while hydraulic heads in a shallow semiconfined aquifer are strongly linked to changes in hydroclimatic conditions during the preceding hydrological year, hydraulic heads in deeper hydrostratigraphic units are largely insensitive to climatic forcings at decadal time scales. Hydraulic heads near Winnipeg had a greater range prior to the 1960s, most prominently during an interval of lowered groundwater levels between 1930 and 1942. When compared to the effects of groundwater withdrawals, it appears that natural variations due to climatic variability in hydraulic heads in the Winnipeg area are relatively insignificant, which suggests that usage remains the most important issue related to groundwater management. This project has also demonstrated that the inclusion of non-traditional parameters related to regional hydroclimate, such as tree-ring records, can improve the performance of empirical groundwater models.

ACKNOWLEDGMENTS

C. Bater and E. Carlson served as extremely capable laboratory and field assistants during 2002.

REFERENCES

Baker, V.R., Webb, R.H. and House, P.K. 2002: The scientific and societal value of paleoflood hydrology; *in* Ancient Floods, Modern Hazards: Principles and Applications of Paleoflood Hydrology, P.K. House, R.H. Webb, V.R. Baker and D.R. Levish (ed.), American Geophysical Union, Washington, p. 1–20.

Booy, C. and Morgan, D.R. 1985: The effect of clustering of flood peaks on a flood risk analysis for the Red River; Canadian Journal of Civil Engineering, v. 12, p. 150–165.

Burn, D.H. and Goel, N.K. 2001: Flood frequency analysis for the Red River at Winnipeg; Canadian Journal of Civil Engineering, v. 28, p. 355–362.

Klemeš, V. 1989: The improbable probabilities of extreme floods and droughts; *in* Hydrology of Disasters, O. Starosolszky and O.M. Melder (ed.), James and James (Science Publishers) Ltd., p. 43–51.

National Research Council 1999: Improving American River Flood Frequency Analysis; National Academy Press, Washington, 132 p.

Ross, A. 1856: The Red River Settlement: Its Rise, Progress, and Present State; Smith, Elder and Co., London.

St. George, S. and Nielsen, E. 2000: Signatures of high-magnitude 19th century floods in *Quercus macrocarpa* tree rings along the Red River, Manitoba, Canada; Geology, v. 28, p. 899–902.

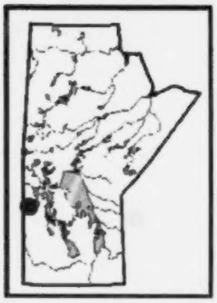
St. George, S. and Nielsen, E. 2002: Hydroclimatic change in southern Manitoba since AD 1409 inferred from tree rings; Quaternary Research, v. 58, p. 103–111.

St. George S. and Nielsen, E. in press: Paleoflood records for the Red River valley, Manitoba, Canada derived from anatomical tree-ring signatures; The Holocene.

Stahle, D. W. 1990: The tree-ring record of false spring in the southcentral USA; PhD thesis, Arizona State University, Phoenix, Arizona, 272 p.

GS-34 KIMBERLITE INDICATOR MINERALS FROM WEST-CENTRAL MANITOBA — 2002 UPDATE (NTS 63C AND 63K)

by J.D. Bamburak and M.A.F. Fedikow[1]



Bamburak, J.D. and Fedikow, M.A.F. 2002: Kimberlite indicator minerals from west-central Manitoba — 2002 update (NTS 63C and 63K); *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 287-294.

SUMMARY

Follow-up investigations of kimberlite indicator minerals (KIM) in west-central Manitoba, released in 2001, have been conducted. The additional sampling was done later that year; and the results of analyses were received early in 2002. This work confirmed that the northern half of the Porcupine Hills contains anomalous quantities of KIM compared to the southern half. The common headwater location of the Little Woody, Rice and Steeprock rivers and of the Homestead and Little Rice creeks appears to be the source area. The KIM are not derived from the Cretaceous Swan River Formation, but may have been eroded from younger Cretaceous beds or from the multiple till sheets that are draped over the Porcupine Hills.

INTRODUCTION

A total of 23 sand and gravel samples (Table GS-34-1) from west-central Manitoba were analyzed for KIM. This work was done as a follow-up to investigations of KIM reported by Bamburak and Fedikow (2001).

A total of 19 samples were taken at the downstream end of sandbars within streams flowing from the Porcupine Hills (Fig. GS-34-1). One sample was collected from the Red Deer River in Saskatchewan, just over the Manitoba boundary. Two samples were prepared from Cretaceous Swan River Formation outcrops; and one sample from a garnet-rich beach sand on Clearwater Lake, north of The Pas.

PREVIOUS WORK

Previous work on kimberlite mineral investigations by government and industry were reported by Bamburak and Fedikow (2001). In the 2001 study, a total of 44 sand and gravel samples, collected in west-central Manitoba from 1997 to 2000, were analyzed for KIM. Most of the samples (39 of them) were taken at the downstream end of sandbars within streams flowing from the Porcupine Hills (Fig. GS-34-1, 2001 stream sediment sample sites).

---

[1] Mount Morgan Resources Ltd., 34 Wellesley Court, Winnipeg, Manitoba, R3P 1X8

Table GS-34-1: West-central Manitoba sediment samples - 2002 study.

Sample No.	Location	NTS	Zone	Easting	Northing	L.S.-Sec.-Twp.-Rge.-Mer.
99-01-PM-001A	Steeprock River Washout Fine	63C11NW	NAD 27 14U	340960	5842410	13-17-43-27-W1
99-01-PM-001B	Steeprock River Washout Coarse	63C11NW	NAD 27 14U	340960	5842410	13-17-43-27-W1
99-01-PM-002A	Steeprock River Rogers Creek	63C11NW	NAD 27 14U	343890	5844710	08-28-43-27-W1
99-01-PM-002B	Coarse	63C11NW	NAD 27 14U	343890	5844710	08-28-43-27-W1
99-01-PM-003A	Steeprock River Rogers Creek Fine	63C11NW	NAD 27 14U	347940	5842820	06-24-43-27-W1
99-01-PM-003B	Steeprock River	63C11NW	NAD 27 14U	347940	5842820	06-24-43-27-W1
99-01-PM-004A	Steeprock River	63C11NE	NAD 27 14U	349475	5842150	14-18-43-26-W1
99-01-PM-004B	Steeprock River	63C11NE	NAD 27 14U	349475	5842150	14-18-43-26-W1
99-01-PM-005A	Steeprock River	63C13SE	NAD 27 14U	330030	5856050	04-31-44-28-W1
99-01-PM-005B	Railway Pier Creek Bridge Upstream	63C13SE	NAD 27 14U	330030	5856050	04-31-44-28-W1
99-01-PM-007A	Railway Pier Creek Bridge Upstream	63C14SW	NAD 27 14U	339875	5853660	13-19-44-27-W1
99-01-PM-007B	Homestead Creek Coarse	63C14SW	NAD 27 14U	339875	5853660	13-19-44-27-W1
99-01-PM-008A	Homestead Creek Fine	63C14SW	NAD 27 14U	343925	5853570	15-21-44-27-W1
99-01-PM-008B	Rice River Inset Stream	63C14SW	NAD 27 14U	343925	5853570	15-21-44-27-W1
99-01-PM-009D	Rice River Dry Sand Bar	63C14SW	NAD 27 14U	343850	5853180	10-21-44-27-W1
99-01-PM-010A	Rice River	63C11SE	NAD 27 14U	355860	5827340	14-34-41-26-W1
99-01-PM-010B	Bell River Upstream	63C11SE	NAD 27 14U	355860	5827340	14-34-41-26-W1
99-01-PM-014	Bell River Downstream	63C11SE	NAD 27 14U	357850	5828100	06-02-42-26-W1
99-01-PM-015	Bell River Above Bridge	63C14SW	NAD 27 14U	331840	5855960	04-32-44-28-W1
99-93-SR-7-1	Tumoff Creek Bridge	63C03NE	NAD 27 14U	356150	5780510	04-11-37-26-W1
99-99-CL-002B	Swan River Composite Sample	63K03SE	NAD 83 14U	355759	5992666	16-35-58-26-W1
99-99-SR-001	Clearwater Lake South Beach	63C03NE	NAD 27 14U	352705	5780075	12-05-37-26-W1
99-01-RD-004	Swan River Ford Bridge	63C13NE	NAD 27 14U	315552	5873501	08-21-46-30-W1

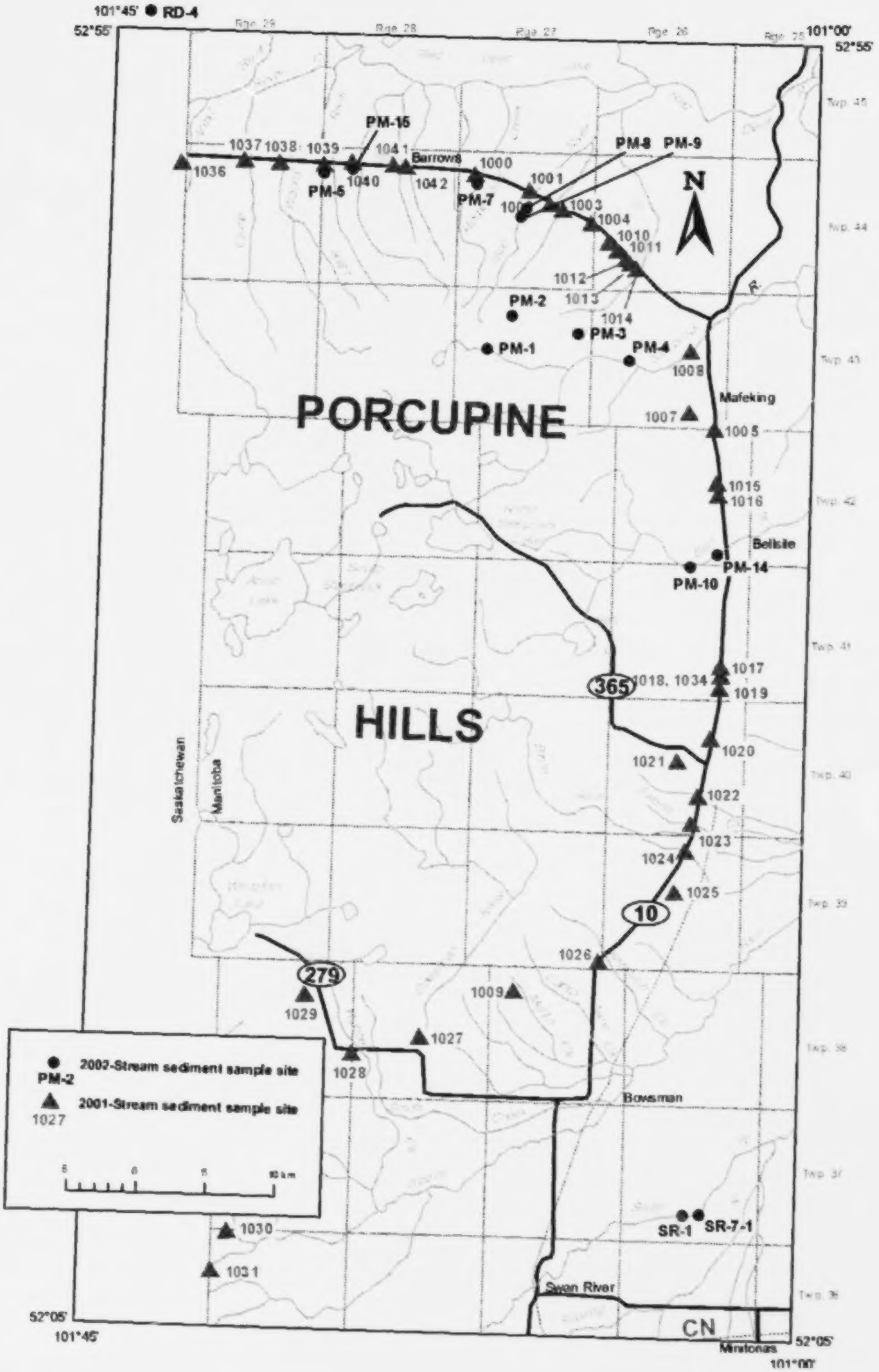

101°45'
RD-4
52°55'
Rge 29
Rge 28
Rge 27
Rge 26
Rge 25
101°00'
52°55'
Twp. 45
Twp. 44
Twp. 43
Twp. 42
Twp. 41
Twp. 40
Twp. 39
Twp. 38
Twp. 37
Twp. 36
N
PM-15
1036
1037
1038
1039
1040
1041
1042
PM-5
Barrows
1000
PM-7
1001
1002
1003
1004
1010
1011
1012
1013
1014
PM-8
PM-9
PM-2
PM-1
PM-3
PM-4
1006
1007
1005
Mafeking
1015
1016
Bellsite
PM-10
PM-14
PORCUPINE
HILLS
365
1018, 1034
1017
1019
1020
1021
1022
1023
1024
1025
10
1026
279
1009
1029
1027
1028
Bowsman
Saskatchewan
Manitoba
SR-1
SR-7-1
1030
1031
Swan River
CN
Minitonas
52°05'
101°45'
52°05'
101°00'
PM-2
2002-Stream sediment sample site
1027
2001-Stream sediment sample site
10 km

Figure GS-34-1: Sampling locations in the Porcupine Hills and vicinity - 2001 and 2002 studies.

SAMPLE COLLECTION, PREPARATION AND ANALYSIS

During the summer of 2001, a total of nineteen 5 kg samples of sand and fine gravel were collected at the downstream end of sandbars within 6 streams flowing from the Porcupine Hills [Fig. GS-34-1 (2002 stream sediment sample sites) and Table GS-34-1]. The purpose of the sampling was to test

1.) the stream beds in which relatively high quantities of KIM had been reported by Bamburak and Fedikow (2001);

2.) the Steeprock River for KIM at several locations to determine whether the Cretaceous Swan River Formation may have contributed anomalous quantities of KIM; and

3.) the Bell River, which had been omitted in the previous survey.

Three additional 5 kg samples in the immediate vicinity of the Porcupine Hills were also analyzed. One sample (99-01-RD-004) was collected in the Red Deer River, just west of the Manitoba–Saskatchewan boundary (Fig. GS-34-1). Two Cretaceous Swan River Formation samples (99-93-SR-7-1 and 99-99-SR-001) were taken 15 km downstream from the town of Swan River (Fig. GS-34-1).

One 5 kg sample, collected 140 km north of the Porcupine Hills area, was also submitted for analysis of KIM. The garnet sand (99-99-CL-002B) was sampled on a beach at the northwest end of Clearwater Lake, 30 km north of The Pas. In the 2001 study, a similar garnet sand sample, taken from a nearby beach on Clearwater Lake, produced a single G10 garnet

When required, the samples were washed to remove organics and coarse sieved to remove pebbles. They were shipped to De Beers Canada Exploration Inc. (De Beers) for processing at the end of the 2001 sampling program. According to Fedikow et al. (2001), processing by De Beers included screening the 5 kg samples at 2.0 mm, with the oversize discarded except for a representative aliquot of the -5.6 to +2.0 mm fraction, which was used for pebble counts. The -2.0 mm size fraction was passed over a 0.3 mm aperture sieve and the -0.3 mm size fraction discarded. The -2.0 to +0.3 mm fraction was concentrated by gravity separation, dried in ovens and further sieved into -2.0 to +1.0 mm, -1.0 to +0.5 mm and -0.5 to +0.3 mm size fractions, which were packaged, labelled and shipped to De Beers' laboratories for further treatment.

These three size fractions were individually separated using the heavy liquid bromoform (specific gravity of 2.86). The heavy fractions that sank through the bromoform were washed and sorted for KIM. Indicator minerals were analyzed by electron microprobe (Fedikow et al., 2001).

Table GS-34-2: Visual mineralogy of the KIM, -2.0 to +1.0 mm size fraction.

Sample No.	TFND	TGA	ROK	OTH	TIL	PM	OTH	TCD	ROS	OTH	TSP
99-01-PM-001A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-001B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-002A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-002B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-003A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-003B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-004A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-004B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-005A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-005B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-007A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-007B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-008A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-008B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-009D	1	0	0	0	1	0	1	0	0	0	0
99-01-PM-010A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-010B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-014	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-015	0	0	0	0	0	0	0	0	0	0	0
99-93-SR-7-1	0	0	0	0	0	0	0	0	0	0	0
99-99-CL-002B	0	0	0	0	0	0	0	0	0	0	0
99-99-SR-001A	0	0	0	0	0	0	0	0	0	0	0
99-01-RD-004	0	0	0	0	0	0	0	0	0	0	0

Abbreviations: TFND, total number of KIMs; **TGA**, total number of kimberlitic garnet grains; **ROK**, number of garnet grains with Remnants Of Kelyphite (surface texture feature) preserved as a crust around the grain; **OTH**, number of other kimberlitic garnet grains; **TIL**, total number of ilmenite grains; **PM**, number of ilmenite grains with Perovskite Mantle (surface texture feature); **OTH**, number of other ilmenite grains; **TCD**, total number of chrome diopside grains; **ROS**, number of chrome diopside grains with Remnants of Original Surface (texture feature); **OTH**, number of other chrome diopside grains; **TSP**, total number of chrome spinel (chromite) grains.

Table GS-34-3: Visual mineralogy of the KIM, -1.0 to +0.5 mm size fraction.

Sample No.	TFND	TGA	ROK	OTH	TIL	PM	OTH	TCD	ROS	OTH	TSP
99-01-PM-001A	1	0	0	0	0	0	0	1	0	1	0
99-01-PM-001B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-002A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-002B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-003A	2	0	0	0	1	0	1	0	0	0	1
99-01-PM-003B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-004A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-004B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-005A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-005B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-007A	2	0	0	0	2	0	2	0	0	0	0
99-01-PM-007B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-008A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-008B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-009D	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-010A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-010B	1	0	0	0	1	0	1	0	0	0	0
99-01-PM-014	1	0	0	0	1	0	1	0	0	0	0
99-01-PM-015	0	0	0	0	0	0	0	0	0	0	0
99-93-SR-7-1	0	0	0	0	0	0	0	0	0	0	0
99-99-CL-002B	0	0	0	0	0	0	0	0	0	0	0
99-99-SR-001A	0	0	0	0	0	0	0	0	0	0	0
99-01-RD-004	0	0	0	0	0	0	0	0	0	0	0

Abbreviations: TFND, total number of KIMs; **TGA**, total number of kimberlitic garnet grains; **ROK**, number of garnet grains with Remnants Of Kelyphite (surface texture feature) preserved as a crust around the grain; **OTH**, number of other kimberlitic garnet grains; **TIL**, total number of ilmenite grains; **PM**, number of ilmenite grains with Perovskite Mantle (surface texture feature); **OTH**, number of other ilmenite grains; **TCD**, total number of chrome diopside grains; **ROS**, number of chrome diopside grains with Remnants of Original Surface (texture feature); **OTH**, number of other chrome diopside grains; **TSP**, total number of chrome spinel (chromite) grains.

Table GS-34-4: Visual mineralogy of the KIM, -0.5 to +0.3 mm size fraction.

Sample No.	TFND	TGA	ROK	OTH	TIL	PM	OTH	TCD	ROS	OTH	TSP
99-01-PM-001A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-001B	1	0	0	0	1	0	1	0	0	0	0
99-01-PM-002A	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-002B	6	0	0	0	0	0	0	0	0	0	6
99-01-PM-003A	5	0	0	0	5	0	5	0	0	0	0
99-01-PM-003B	1	0	0	0	0	0	0	0	0	0	1
99-01-PM-004A	2	0	0	0	0	0	0	0	0	0	2
99-01-PM-004B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-005A	3	0	0	0	0	0	0	0	0	0	3
99-01-PM-005B	2	0	0	0	0	0	0	2	0	2	0
99-01-PM-007A	4	0	0	0	4	0	4	0	0	0	0
99-01-PM-007B	0	0	0	0	0	0	0	0	0	0	0
99-01-PM-008A	3	0	0	0	0	0	0	0	0	0	3
99-01-PM-008B	2	1	0	1	0	0	0	0	0	0	1
99-01-PM-009D	4	0	0	0	1	0	1	0	0	0	3
99-01-PM-010A	3	0	0	0	2	0	2	0	0	0	1
99-01-PM-010B	4	1	0	1	1	0	1	1	0	1	1
99-01-PM-014	1	0	0	0	0	0	0	0	0	0	1
99-01-PM-015	0	0	0	0	0	0	0	0	0	0	0
99-93-SR-7-1	0	0	0	0	0	0	0	0	0	0	0
99-99-CL-002B	0	0	0	0	0	0	0	0	0	0	0
99-99-SR-001A	0	0	0	0	0	0	0	0	0	0	0
99-01-RD-004	4	0	0	0	0	0	0	0	0	0	4

Abbreviations: TFND, total number of KIMs; **TGA**, total number of kimberlitic garnet grains; **ROK**, number of garnet grains with Remnants Of Kelyphite (surface texture feature) preserved as a crust around the grain; **OTH**, number of other kimberlitic garnet grains; **TIL**, total number of ilmenite grains; **PM**, number of ilmenite grains with Perovskite Mantle (surface texture feature); **OTH**, number of other ilmenite grains; **TCD**, total number of chrome diopside grains; **ROS**, number of chrome diopside grains with Remnants of Original Surface (texture feature); **OTH**, number of other chrome diopside grains; **TSP**, total number of chrome spinel (chromite) grains.

VISUAL MINERALOGY AND MINERAL CHEMISTRY

In the 2002 study samples, one kimberlitic grain was recovered in the -2.0 to +1.0 mm size fraction (Table GS-34-2), 7 grains were recovered in the -1.0 to +0.5 mm size fraction (Table GS-34-3), and 45 grains were recovered in the -0.5 to +0.3 mm size fraction (Table GS-34-4). Original surface remnants were not observed on any of the kimberlitic grains recovered in the 2002 study.

The picked KIM were analyzed with an electron microprobe and classified. The resultant mineral chemistry is listed in Table GS-34-5 for the -2.0 to +1.0 mm size fraction, in Table GS-34-6 for the -1.0 to +0.5 mm size fraction and in Table GS-34-7 for the -0.5 to +0.3 mm size fraction.

The KIM from the 2002 study comprise 22 chrome spinel grains, 7 Mg-ilmenite grains, 3 chrome diopside grains, 1 titanian chrome pyrope and 1 non-titanian chrome pyrope. These kimberlitic grains are more or less evenly distributed. The samples collected from the streams draining the northern slope of the Porcupine Hills are marked by an assemblage of primarily chrome spinel, chrome diopside, Mg-ilmenite and 1 G9 garnet (from site PM-8). Sites PM-1 through PM-4 represent a series of samples collected from an east-west transect on the Steeprock River and its tributaries (south of the north slope of the Porcupine Hills). These sites are also characterized by chrome spinel (n=14) and Mg-ilmenite (n=1). The samples from sites PM-10 and PM-14 along the Bell River, south and east of the Steeprock River also contain KIM. Site PM-10 contains a G11 non-titanian chrome pyrope, 2 chrome spinel and a chrome diopside; PM-14 contains 1 chrome spinel grain.

DISCUSSION

The results of the analyses for KIM are summarized in Table GS-34-8.

- The two Swan River Formation samples (99-93-SR-7-1 and 99-99-SR-001) collected in the Swan River valley did not contain KIM. One of the samples was a bulk channel sample collected over a 5 m vertical section. The absence of KIM in the Swan River Formation samples can be contrasted with the numbers of KIM found within present day stream sediments from the Steeprock and Bell river basins and those on the north slope of the Porcupine Hills, described above. This indicates that the Swan River Formation did not contribute KIM to the stream sediments.
- Samples taken from the coarse and fine portions of the same streambed do not show any marked difference in the abundance of KIM. Sample pairs 99-01-PM-007A and -007B, 99-01-PM-001A and -001B, and 99-01-PM-002A and -002B do not show any trends.
- In the 2001 study for the Porcupine Hills (Fig. GS-34-1, Table GS-34-9), one half of the ten KIM in the -1.0 to +0.5 mm grain-size range (including a G9 garnet and a diamond inclusion spinel) were found in streams draining the northern slope of the Hills (99T-1038 to 99T-1004). Secondly, almost 80% of the indicators in the -0.5 to +0.3 size fraction were from streams that share the same headwaters area (Little Woody, Rice and Steeprock rivers and Homestead and Little Rice creeks).
- The relative abundance of KIM in the same streams in the 2001 study, as was described above, was higher than in this study. This may have been due to the time of year when the sampling was done. Water flow may have been greater during the spring of 1997 than in mid-summer of 2001.
- No KIM were found in the garnet sand sample (99-99-CL-002B) from a beach on Clearwater Lake, north of The Pas. In the 2001 survey, a garnet sand sample (99T-1035), taken from a nearby beach on Clearwater Lake, contained a single G10 garnet in the -0.5 to +0.3 mm size fraction.

Table GS-34-5: Mineral chemistry of the KIM, -2.0 to +1.0 mm size fraction.

Sample No.	MnO	Na_2O	Al_2O_3	FeO	SiO_2	TiO_2	CaO	Cr_2O_3	MgO	TOTAL	Classification
99-01-PM-009D	0.18	0	0.19	40.28	0.06	50.55	0	0.17	7.94	99.37	Mg-ilmenite

Table GS-34-6: Mineral chemistry of the KIM, -1.0 to +0.5 mm size fraction.

Sample No.	MnO	Na_2O	Al_2O_3	FeO	SiO_2	TiO_2	CaO	Cr_2O_3	MgO	TOTAL	Classification
99-01-PM-003A	0.21	0	0.42	34.48	0.09	50.9	0	1.24	10.94	98.28	Mg-ilmenite
99-01-PM-007A	0.23	0	0.34	37.77	0.06	51.01	0	0.32	9.8	99.53	Mg-ilmenite
99-01-PM-007A	0.15	0.11	0.48	39.08	0.09	50.36	0.05	0.46	9.31	100.1	Mg-ilmenite
99-01-PM-010B	0.26	0.02	0.36	32.68	0.04	52.96	0	1.07	11.74	99.13	Mg-ilmenite
99-01-PM-014	0.18	0	7.15	27.67	0.21	3.73	0.01	47.23	14.19	100.38	ilmenite
99-01-PM-003A	0.39	0.07	12.58	29.76	0	0.22	0	47.63	9.09	99.73	chrome spinel
99-01-PM-001A	0.09	1.17	1.88	2.82	54.03	0.08	22.69	1.39	15.22	99.38	chrome andradite

Table GS-34-7: Mineral chemistry of the KIM, -0.5 to +0.3 mm size fraction.

Sample No.	MnO	Na_2O	Al_2O_3	FeO	SiO_2	TiO_2	CaO	Cr_2O_3	MgO	TOTAL	Classification
99-01-PM-005B	0.12	0.98	1.69	3.62	55.31	0.11	22.15	1.13	16.34	101.45	chrome diopside
99-01-PM-005B	0.09	0.94	1.81	2.94	55.06	0.11	22.6	1.4	16.47	101.41	chrome diopside
99-01-PM-010B	0.07	0.42	1.19	2.12	54.37	0.13	23.66	1.29	16.63	99.88	chrome diopside
99-01-PM-008B	0.51	0.14	19.36	7.89	43.22	0.09	5.15	4.72	20.63	101.71	non-titanian Cr-pyrope (G9)
99-01-PM-010B	0.22	0.02	18.16	7.19	41.97	0.39	7.11	6.7	19.76	101.51	titanian Cr-pyrope (G11)
99-01-PM-003A	2.19	0.12	0	48.46	0.07	49.87	0.01	0	0.11	100.85	ilmenite
99-01-PM-007A	0.47	0.07	0	48.91	0.03	50.72	0.01	0.03	0.7	100.95	ilmenite
99-01-PM-007A	2.11	0.07	0	46.9	0.04	51.01	0.01	0	0.16	100.31	ilmenite
99-01-PM-010A	0.29	0	0.65	34.68	0.06	52.01	0	0.48	12.21	100.38	Mg-ilmenite
99-01-PM-010A	0.3	0	0.06	48.32	0	48.47	0	0.14	2.28	99.59	ilmenite
99-01-PM-010B	0.37	0.02	0.59	42.13	0.01	48.69	0	0	8.57	100.39	Mg-ilmenite
99-01-PM-001B	0.34	0	0	92.93	0.19	0	0.04	0.02	0	93.51	magnetite
99-01-PM-003A	0.07	0	0.07	93.46	0.08	0.02	0.04	0	0	93.74	magnetite
99-01-PM-003A	0.11	0	0	93.16	0.06	0.07	0.03	0.14	0.06	93.64	magnetite
99-01-PM-003A	0.07	0	0.12	94.65	0.12	0.09	0.01	0.06	0.15	95.25	magnetite
99-01-PM-003A	0.1	0.15	0.38	94.59	0.12	0	0.09	0.09	0.3	95.82	magnetite
99-01-PM-007A	0.02	0	0.34	94.01	0.03	0.06	0	0.08	0.04	94.58	magnetite
99-01-PM-009D	0.08	0	0.07	93.11	0.01	0	0.01	0.06	0	93.35	magnetite
99-01-PM-007A	0	0.18	0.07	0.15	0.04	99.24	0	0.19	0.01	99.88	rutile
99-01-PM-008A	1.88	0	0	45.9	0.04	52.13	0	0.02	0.33	100.3	ilmenite
99-01-PM-009D	0.32	0	0.04	47.49	0.1	50.46	0	0.1	1.46	99.97	ilmenite
99-01-PM-005A	0.14	0	0	93.63	0.15	0	0.02	0	0	93.95	magnetite
99-01-PM-009D	0.03	0	0	93.26	0.1	0.12	0	0	0	93.52	magnetite
99-01-PM-009D	0.18	0	0	93.63	0.01	0.1	0	0.04	0.02	93.98	magnetite
99-01-PM-002B	0.59	0.17	8.37	31.38	0.01	0.18	0	53.29	5.63	99.62	chrome spinel
99-01-PM-002B	0.5	0.21	13.06	35.66	0.25	0.2	0.02	43.66	6.48	100.04	chrome spinel
99-01-PM-002B	0.18	0	17.53	17.14	0.18	0.53	0	49.55	14.25	99.36	chrome spinel
99-01-PM-002B	0.38	0	10.8	37.72	0.06	0.18	0	45.05	5.33	99.51	chrome spinel
99-01-PM-002B	1.06	0.07	15.66	38.62	0.11	0.37	0	42.69	1.4	99.99	chrome spinel
99-01-PM-002B	0.37	0.06	17.95	27.2	0.04	0.38	0	44.06	9.18	99.24	chrome spinel
99-01-PM-003B	0.21	0	19.34	26.85	0.03	0.44	0	42.95	10.26	100.09	chrome spinel
99-01-PM-004A	0.31	0.11	17.63	30.49	0.13	0.66	0	42.16	8.94	100.42	chrome spinel
99-01-PM-004A	0.52	0.25	13.65	24.99	0.09	0.18	0.01	53.73	7.32	100.74	chrome spinel
99-01-PM-005A	0.43	0	22.01	36.75	0.06	0.2	0.01	33.6	7.02	100.08	chrome spinel
99-01-PM-005A	0.4	0.02	11.77	31.02	0.08	0.19	0	48.23	8.46	100.17	chrome spinel
99-01-PM-008A	0.32	0.06	18.11	32.81	0.1	0.16	0	39.91	8.32	99.79	chrome spinel
99-01-PM-008A	0.44	0	7.83	37.47	0.04	0	0	51.82	1.5	99.11	chrome spinel
99-01-PM-008B	0.13	0	17.25	21.85	0.1	1.77	0	43.18	15.55	99.83	chrome spinel
99-01-PM-010A	0.13	0	31.07	17.37	0	0.38	0	38.86	13.5	101.31	chrome spinel
99-01-PM-010B	0.14	0.23	17.76	16.6	0.04	0.19	0	51.85	13.72	100.54	chrome spinel
99-01-PM-014	0.3	0	17.01	26.49	0.06	0.53	0	43.94	9.64	97.98	chrome spinel
99-01-RD-004	0.31	0	6.63	21.3	0.07	0	0	63.13	7.5	98.94	chrome spinel
99-01-RD-004	0.38	0.02	5.87	41.95	0.01	0.31	0	45.37	4.68	98.59	chrome spinel
99-01-RD-004	0.29	0.02	18.94	29.85	0.13	1.17	0	39.51	9.44	99.36	chrome spinel
99-01-RD-004	0.44	0	2.87	44.33	0.04	0.45	0	46.35	3.09	97.58	chrome spinel

CONCLUSIONS

This brief KIM follow-up study indicates that the source for the kimberlitic grains is north and/or northwest of the streams sampled in the Porcupine Hills. This could indicate that the Fort a la Corne kimberlites, in Saskatchewan, are the source for these KIM, or that another source exists north of the Porcupine Hills.

- The Swan River Formation is not the source of the KIM that have been found in the Porcupine Hills. The Lower Cretaceous Swan River Formation is exposed along cut banks in both the Steeprock and Bell rivers, this makes these river basins unlikely candidates for KIM exploration.
- The present stream sediments are derived from the multiple tills and glaciofluvial deposits that drape the Porcupine Hills. The source of these tills and glaciofluvial deposits is open to speculation. More till sampling north of the Hills would be required to determine whether there is a local kimberlite source in Manitoba.
- A more likely source for the KIM within the tills and glaciofluvial deposits on the Porcupine Hills may have been from the beds of preglacial and glacial streams that flowed in a southeasterly direction from the Fort a la Corne area in Saskatchewan (280 km west-northwest). Sample 99-01-RD-004, collected from the Red Deer River (SK), also suggests a western source for the KIM in Saskatchewan, possibly Fort a la Corne.

Table GS-34-8: Summary of kimberlite indicator-mineral occurrences - 2002 study.

Sample No.	Location	Kimberlite Indicator Grain Size		
		-2.0 to +1.0 mm	-1.0 to +0.5 mm	-0.5 to +0.3 mm
Porcupine Hills (clockwise)				
99-01-RD-004	**Red Deer River (Sask.)**	**0**	**0**	**4**
99-01-PM-005A	**Railway Pier Creek Bridge**	**0**	**0**	**3**
99-01-PM-005B	**Upstream**	**0**	**0**	**2**
99-01-PM-015	**Railway Pier Creek Bridge**	0	0	0
99-01-PM-007A	**Upstream**	**0**	**2**	**4**
99-01-PM-007B	Turnoff Creek Bridge	0	0	0
99-01-PM-008A	**Homestead Creek Coarse**	**0**	**0**	**3**
99-01-PM-008B	Homestead Creek Fine	**0**	**0**	**2**
99-01-PM-009D	**Rice River Inset Stream**	**1**	**0**	**4**
99-01-PM-002A	**Rice River Dry Sand Bar**	0	0	0
99-01-PM-002B	**Rice River**	**0**	**0**	**6**
99-01-PM-001A	Steeprock River Rogers Creek Coarse	**0**	**1**	**0**
99-01-PM-001B	**Steeprock River Rogers Creek Fine**	**0**	**0**	**1**
99-01-PM-003A	**Steeprock River Washout Fine**	**0**	**2**	**5**
99-01-PM-003B	**Steeprock River Washout Coarse**	**0**	**0**	**1**
99-01-PM-004A	**Steeprock River**	**0**	**0**	**2**
99-01-PM-004B	**Steeprock River**	0	0	0
99-01-PM-014	**Steeprock River**	**0**	**1**	**1**
99-01-PM-010A	Steeprock River	**0**	**0**	**3**
99-01-PM-010B	**Bell River Above Bridge**	**0**	**1**	**4**
99-93-SR-7-1	**Bell River Upstream**	0	0	0
99-99-SR-001	**Bell River Downstream**	0	0	0
	Swan River Composite Sample			
External Sites	Swan River Ford Bridge			
99-99-CL-002B		0	0	0

- Both the 2001 and 2002 studies indicate that the abundance of KIM appears to be gradually declining in a southeast direction, across the Porcupine Hills.
- Clearwater Lake garnet sands do not appear to have been derived from a nearby kimberlite source.

ACKNOWLEDGMENTS

De Beers Canada Exploration Inc. is thanked for concentrating, picking and analyzing (by electron microprobe) the KIM, free of charge. In keeping with the usual confidentiality practice of the MGS, the sampling site locations were not revealed to De Beers.

B. Lenton is acknowledged for the preparation of Figure GS-34-1.

REFERENCES

Bamburak, J. D. and Fedikow, M.A.F. 2001: Kimberlite indicator minerals from west-central Manitoba (NTS 62N, 63C, 63K); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Open File Report OF2001-3, 11 p. plus 1 CD-ROM.

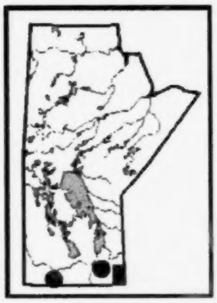
Fedikow, M.A.F., Nielsen, E., Conley, G.G. and Lenton, P.G. 2001: Operation Superior: kimberlite indicator mineral survey results (2000) for the northern half of the Knee Lake greenstone belt, northern Superior Province, Manitoba (NTS 53M/1,2,3,7 and 53L/15); Manitoba Industry, Trade and Mines, Geological Survey, Open File Report OF2001-5, 59 p.

Table GS-34-9: Kimberlite indicator-mineral summary from Bamburak and Fedikow (2001).

Sample No.	Location	Kimberlite Indicator Grain Size -1.0 to +0.5 mm	-0.5 to +0.3 mm	NTS	Zone	Easting	Northing	L.S.-Sec.-Twp.-Rge.-Mer.
Porcupine Hills (clockwise)								
99T-1036	Armit River (Sask.)	0	0	63C13SE	NAD 27 14U	319590	5856300	02-36-44-30-W1
99T-1037	Camp Seven Creek	0	0	63C13SE	NAD 27 14U	324190	5856370	07-33-44-29-W1
99T-1038	**Woody Creek (Little Woody River)**	**0**	**3**	63C13SE	NAD 27 14U	326710	5856230	04-35-44-29-W1
99T-1039	**Railway Pier Creek Bridge**	**1**	**11**	63C13SE	NAD 27 14U	330030	5856050	04-31-44-28-W1
99T-1040	**Turnoff Creek Bridge**	**0**	**7**	63C14SW	NAD 27 14U	331840	5855960	04-32-44-28-W1
99T-1041	**Barrows West Creek Bridge**	**1**	**0**	63C14SW	NAD 27 14U	334920	5856050	05-34-44-28-W1
99T-1042	Whisky Creek Bridge	0	0	63C14SW	NAD 27 14U	335710	5855980	02-34-44-28-W1
99T-1000	**Homestead Creek Bridge**	**1**	**27**	63C14SW	NAD 27 14U	340750	5855110	15-30-44-27-W1
99T-1001	**Rice River Bridge**	**0**	**12**	63C14SW	NAD 27 14U	344530	5854090	04-27-44-27-W1
99T-1002	**Centre Rice Creek Culvert**	**1**	**1**	63C14SW	NAD 27 14U	346140	5853140	12-23-44-27-W1
99T-1003	**Cement Culvert Creek (Little Rice)**	**0**	**4**	63C14SW	NAD 27 14U	346980	5852670	07-23-44-27-W1
99T-1004	**(Little) Rice Creek Bridge**	**1**	**5**	63C14SW	NAD 27 14U	348850	5851760	15-13-44-27-W1
99T-1010	Baden West Creek Bridge	0	0	63C14SE	NAD 27 14U	350190	5850360	02-18-44-26-W1
99T-1011	Baden East Creek (South of hamlet)	0	0	63C14SE	NAD 27 14U	350200	5849850	10-07-44-26-W1
99T-1012	Sting Creek	0	0	63C14SE	NAD 27 14U	351620	5848880	03-08-44-26-W1
99T-1013	Beaver Dam Creek	0	0	63C14SE	NAD 27 14U	352110	5848310	16-05-44-26-W1
99T-1014	77 Creek	0	0	63C14SE	NAD 27 14U	353270	5847450	07-04-44-26-W1
99T-1008	Steeprock River Old Crossing	0	0	63C11NE	NAD 27 14U	356110	5842530	06-23-43-26-W1
99T-1007	**Mafeking Creek Ford**	**0**	**1**	63C11NE	NAD 27 14U	356010	5838400	11-02-43-26-W1
99T-1005	Smith (Morgan) Creek Bridge	0	0	63C11NE	NAD 27 14U	358070	5837000	14-35-42-26-W1
99T-1015	**Raven Creek**	**0**	**2**	63C11NE	NAD 27 14U	358020	5833170	10-23-42-26-W1
99T-1016	**Nowhere Creek**	**0**	**1**	63C11SE	NAD 27 14U	358100	5832020	15-14-42-26-W1
99T-1017	Dry Creek	0	0	63C11SE	NAD 27 14U	358120	5821610	08-14-41-26-W1
99T-1018	Glade Creek	0	0	63C11SE	NAD 27 14U	358120	5821230	01-14-41-26-W1
99T-1034	**New Creek**	**0**	**2**	63C11SE	NAD 83 14U	358127	5821407	07-14-41-26-W1
99T-1019	**Post Creek**	**2**	**1**	63C11SE	NAD 27 14U	358050	5819370	01-11-41-26-W1
99T-1020	**Unnamed Creek**	**0**	**4**	63C06NE	NAD 27 14U	357320	5815050	06-26-40-26-W1
99T-1021	Steeprock Road Creek	0	0	63C06NE	NAD 27 14U	355150	5813340	05-22-40-26-W1
99T-1022	**Turnoff Creek**	**0**	**2**	63C06NE	NAD 27 14U	356400	5811010	16-10-40-26-W1
99T-1023	Rusty Creek	0	0	63C06NE	NAD 27 14U	355960	5809010	10-03-40-26-W1
99T-1024	**Birch River (Primrose Wayside Park)**	**1**	**0**	63C06NE	NAD 27 14U	355670	5807090	07-34-39-26-W1
99T-1025	Iron Creek	0	0	63C06SE	NAD 27 14U	353860	5804420	11-21-39-26-W1
99T-1026	Kematch River	0	0	63C06SE	NAD 27 14U	349370	5799250	08-01-39-27-W1
99T-1009	Mudlen Creek Discovery	0	0	63C06SW	NAD 27 14U	343410	5796870	13-29-38-27-W1
99T-1027	**Bowsman River**	**1**	**0**	63C06SW	NAD 27 14U	336640	5793750	16-16-38-28-W1
99T-1028	**Hubbell Creek**	**0**	**4**	63C06SW	NAD 27 14U	331860	5792560	04-18-38-28-W1
99T-1029	**Trout Creek**	**1**	**0**	63C04NE	NAD 27 14U	328200	5786210	16-22-37-29-W1
99T-1030	Woody Creek	0	0	63C04NE	NAD 27 14U	322750	5779910	16-31-36-29-W1
99T-1031	Hart Creek	0	0	63C04SE	NAD 27 14U	321450	5777200	05-30-36-29-W1
External Sites								
99T-1006	German Lake Salt Spring	0	0	63C15SW	NAD 27 14U	372630	5846460	03-04-44-24-W1
99T-1043	**East Favel River**	**0**	**1**	63C03SE	NAD 27 14U	360750	5765700	14-19-35-25-W1
99T-1032	Fishing River Gravel Pit	0	0	62N08NE	NAD 83 14U	425200	5699233	06-33-28-19-W1
99T-1033	Sulphur Spring Creek Bridge	0	0	62N07SE	NAD 27 14U	381750	5689700	01-36-27-24-W1
99T-1035	**Clearwater Lake**	**0**	**1**	63K03SE	NAD 83 14U	355759	5992666	16-35-58-26-W1

GS-35 AGGREGATE RESOURCES IN THE RURAL MUNICIPALITIES OF STE. ANNE AND TURTLE MOUNTAIN AND IN THE BUFFALO POINT AREA, MANITOBA

by H.D. Groom



Groom, H.D. 2002: Aggregate resources in the rural municipalities of Ste. Anne and Turtle Mountain and in the Buffalo Point area; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 295-302.

SUMMARY

Aggregate inventories were carried out in the rural municipalities of Ste. Anne and Turtle Mountain, in the Buffalo Point area and on several crown land parcels in southeastern Manitoba. Office compilation was followed by site inspection and aggregate sampling. Samples were field sieved and a representative portion of the fine fraction sent to Winnipeg for processing. Approximately 350 sites were visited.

INTRODUCTION

This summer's aggregate inventories were carried out in three areas of southern Manitoba:

- The Rural Municipality (R.M.) of Ste. Anne, approximately 30 km southeast of the City of Winnipeg.
- The R.M. of Turtle Mountain, approximately 230 km southwest of Winnipeg.
- Seven candidate sites for the Areas of Special Interest (ASI) program in southeastern Manitoba. The largest of these is the Buffalo Point ASI in the extreme southeast corner of the province. The other six are Steve's Shape, Mensino Ridge and small additions to the existing ASIs of Vassar, Lone Sand East, St. Labre and North Hugo Lake.

The two municipalities were chosen for assessment as current aggregate information is required for inclusion in upcoming municipal development plans. The aggregate information gathered from the ASIs will be part of the mineral assessment of these areas.

RURAL MUNICIPALITY OF STE. ANNE

The R.M. of Ste. Anne lies approximately 30 km southeast of Winnipeg. It covers five townships (Twp. 8, Rge. 6–8, E 1st Mer. and Twp. 7, Rge. 7–8, E 1st Mer.) and is located on NTS map sheets 62H9 and 10 (Fig. GS-35-1). The

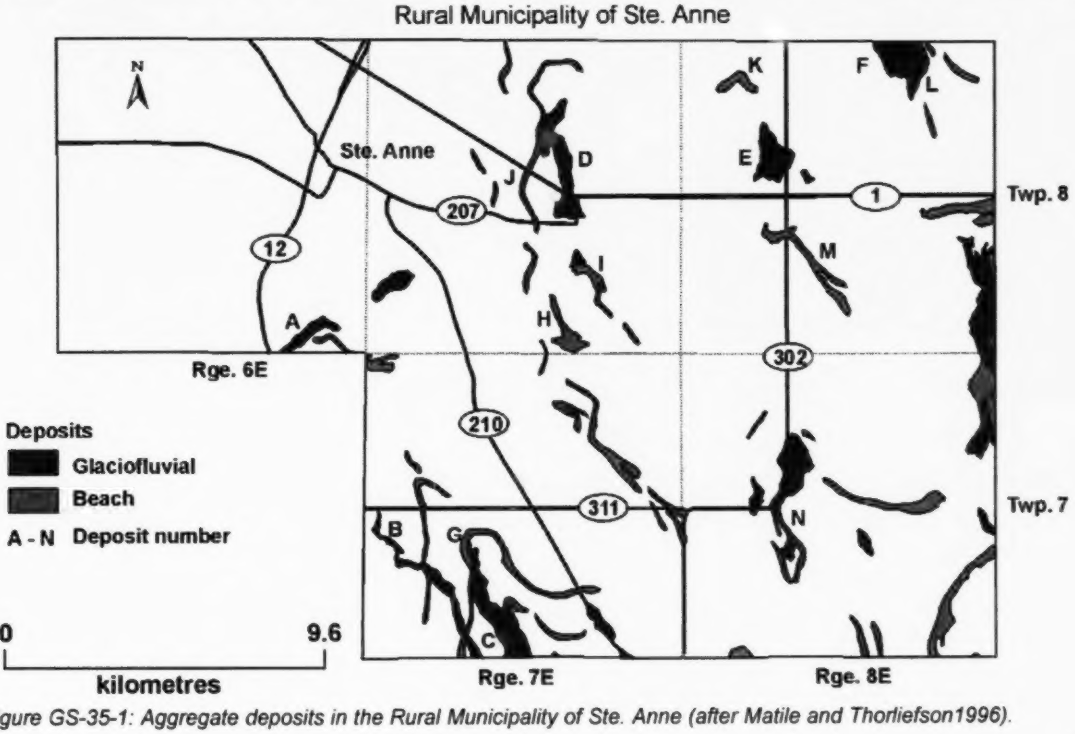


Figure GS-35-1: Aggregate deposits in the Rural Municipality of Ste. Anne (after Matile and Thorliefson1996).

major service centre is the town of Ste. Anne. Provincial highways 1 and 12, Provincial roads (PR) 207, 210, 302 and 311 as well as section roads give good access to most of the municipality. While the municipality is still largely rural and farming is a major source of income, the proximity to Winnipeg has resulted in a great increase in small acreages, subdivision developments, golf courses and campgrounds.

The R.M. is underlain by dolomitic limestones and dolomites of the Ordovician Red River Formation. Overburden thicknesses range from less than 30 m in the east to greater than 50 m along the western edge of the municipality (Little, 1980). No bedrock is used as aggregate in the municipality.

The R.M. of Ste. Anne is included on the Steinbach sheet (Matile and Thorliefson, 1996) of the Prairie NATMAP series, which mapped the surficial sediments of southeastern Manitoba at a scale of 1:100 000. The surficial geology and aggregate resources of the municipality had been mapped previously at a 1:50 000 scale (Matile and Conley, 1979).

The northwestern portion of the municipality is underlain by thick deposits of lacustrine clay. The sand and gravel deposits are primarily glaciofluvial eskers and outwash plains and lacustrine beach deposits. The eastern part of the municipality has large areas of organic accumulations, several of which are sources of high quality peat moss. These deposits resulted from late glacial and early postglacial events. The last ice flow came from the northwest depositing esker and glaciofluvial materials. Glacial Lake Agassiz formed as the ice retreated. Clay was deposited in the deeper parts of the lake and beach ridges formed at the shores. Organic deposits formed in poorly drained areas after glacial Lake Agassiz retreated from the area.

Aggregate Inventory Methodology

The aggregate inventory was carried out in two stages; office compilation followed by field work. Previously mapped deposits were transferred onto 1:20 000 township photomosaics (1997 orthophotos). The township mosaics were used as a base on which to compile aggregate information from several sources:

1) active pit locations – Mines Branch quarry database

2) quarry lease and withdrawn locations – Mines Branch plat books

3) crown versus private ownership – Manitoba Crown Lands Branch database

4) pit and sample locations - Geological Survey Pleistocene database

5) pit and sample locations - Department of Highways block files

Gravel pits, roadcuts and natural exposures were examined during the first part of the field examination. Pits were examined for type of material, degree of depletion and active/inactive/depleted status. Unopened portions of deposits were inspected and land uses that would limit aggregate extraction noted. Site locations were taken by GPS using UTM co-ordinates, as well as by section-township-range notation.

Aggregate samples were processed in two stages. In the field, samples that weighed between 75 and 100 kg were passed through 6-inch (15.2 cm), 3-inch (7.6 cm), 1½-inch (3.8 cm) and ¾-inch (1.9 cm) screens. The weights of the 3-inch, 1½-inch, ¾-inch and less than ¾-inch fractions were recorded. The relative abundance of the greater than 6-inch material, as well as deleterious material such as shale or concretions, was noted. Pebble counts on the 1½-inch to 3-inch fraction were done in the field. A representative sample of the less than ¾-inch fraction was taken for processing by the Material and Research Branch of the Department of Transportation and Government Services (Highways) under the terms of the cooperative agreement initiated in 1998. Sieve intervals and grain-size terms are given in Figure GS-35-2.

Aggregate Resources

The sand and gravel deposits in the R.M. of Ste. Anne are primarily glaciofluvial eskers and outwash plains and lacustrine beach deposits. In several locations, the beach ridges overlie or flank the glaciofluvial deposits. Figure GS-35-1 shows the location and type of deposits in the R.M. of Ste. Anne. The deposits are well distributed across the central and eastern parts of the municipality and almost all of them have been used for aggregate production either currently or at some time in the past. In general, the gravel lithology is a mix of carbonate and Precambrian clasts, with the carbonate fraction ranging between 65 and 85%. Most of the gravel is privately owned. Of the crown-owned sites, two are under lease and the other five are operated under quarry permits. Twenty-six pits have been active in the last five years. Two of these have been rehabilitated, one as a golf course and the other as a resort, and one has been removed from mining at the request of the municipality.

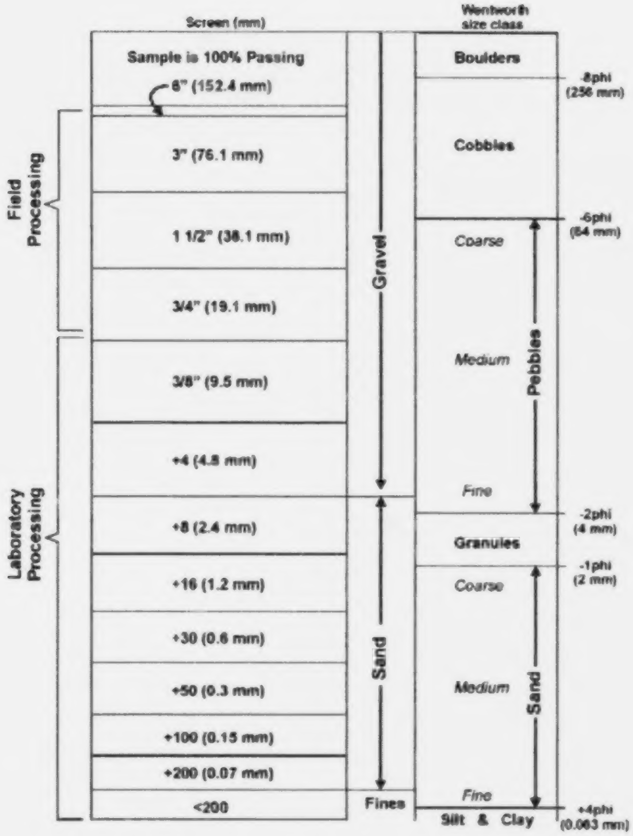

Screen (mm)
Wentworth size class
Sample is 100% Passing
6" (152.4 mm)
3" (76.1 mm)
1 1/2" (38.1 mm)
3/4" (19.1 mm)
3/8" (9.5 mm)
+4 (4.8 mm)
+8 (2.4 mm)
+16 (1.2 mm)
+30 (0.6 mm)
+50 (0.3 mm)
+100 (0.15 mm)
+200 (0.07 mm)
<200
Field Processing
Laboratory Processing
Gravel
Sand
Fines
Boulders
-8phi (256 mm)
Cobbles
-6phi (64 mm)
Coarse
Medium
Fine
Pebbles
-2phi (4 mm)
Granules
-1phi (2 mm)
Coarse
Medium
Fine
Sand
+4phi (0.063 mm)
Silt & Clay

Figure GS-35-2: Grain-size classification and sieve intervals (after Folk, 1974).

Deposits

There are active pits in five glaciofluvial deposits in the municipality. Most of these pits are well established and gravel is currently being extracted from below the water table in several of them.

Deposit A (Fig. GS-35-1) in Twp. 8, Rge. 6, E. 1st Mer. (abbreviated 8-6-E1) has one active pit. The pit is water filled and reported to be greater than 8 m deep. The pit will continue to expand westward. The deposit is notable for the presence of shale. The amounts are minor but it is the only deposit in the municipality to contain any shale. The aggregate continues southwest across the section road but the owners of the gravel do not wish to open the deposit for large-scale extraction. The linear deposit (B) running through the southwest corner of 7-7-E1 is an esker. The gravel pits in this deposit have been in existence for a long time but have recently been reactivated and material is now being removed from below the water by dragline. There is a reported 15 m of gravel below the water table. Deposit C, in 7-7-E1, has been extensively mined. The pits range from 2 to greater than 6 m deep. The deposit is primarily fine sand but there are pockets of gravel suitable for crushing.

The pit in Deposit D, in 8-7-E1, was active in the last five years but the southern portion of the pit has been rehabilitated. There is now a resort with cottages beside a pond.

There are active pits in two glaciofluvial deposits in 8-8-E1. The southern deposit (E) has two gravel pits. The crown pit at the north end of the deposit is up to 4 m deep and water covers the pit floor in places. The material is mostly sand but there are areas of gravel and there are boulder piles on site. The pit to the south is adjacent to a campground and has recently been rehabilitated due to safety and land-use compatibility concerns. The northern glaciofluvial deposit (F) is being worked by dragline to remove material from below the water table. There is a very good range of material sizes in this deposit.

There are active pits in seven beach deposits in the municipality. The pits are generally 1.5 to 2.5 m deep and most often overlie till. Occasionally they flank and partially overlie glaciofluvial deposits.

Deposit G, in 7-7-E1, has one active pit at its north end. The pit has approximately 1 m of pebble gravel over sand. The pit has been rehabilitated at the south end, where it is depleted, and extraction continues to the north.

There are recently active pits in three deposits in 8-7-E1. Deposit H is depleted at the south end but there has been recent extraction at the north end where there is about 1.5 m of sandy pebble gravel. This pit is owned by the municipality. The main ridge of Deposit I has been depleted; there has been some minor removal of pebbly sand from the south end of this deposit. The one active pit is held under quarry lease. The pit is large and very shallow (less than 1 m). The material is primarily sand, which the leaseholder says he works into the heavy clay soil on his farm. While Deposit J has not been actively mined since 1999, and much of its length has been depleted or sterilized by residential development, there are still areas of aggregate reserves. From existing pits, the material in the deposit is fine pebble gravel, 1 to 2 m thick.

There are active pits in two of the beach deposits in 8-8-E1 and a recently active pit in another beach deposit. The pit in deposit K is about 1.5 m deep and till is evident in the floor. The deposit is nearing depletion. Deposit L is being worked southward along the ridge. The pit in this deposit is about 2 m deep. The material is very sandy and two test pits along the ridge indicate the proportion of sand increases to the south. Deposit M has several old pits along its length. The material is again very sandy. The deposit is nearly depleted at its south end with minor amounts of material being used in the rehabilitation of some of the old pits.

Deposit N is a large deposit that has been extensively mined at the north end. There is one pit adjacent to PR 302 that is near depletion. Northeast of this pit, old pits have been reactivated and are being expanded southwards. The pits are shallow and there is about 1.5 m of material that ranges from fine pebble gravel to pebbly sand.

RURAL MUNICIPALITY OF TURTLE MOUNTAIN

The R.M. of Turtle Mountain lies approximately 200 km southwest of Winnipeg. It covers slightly less than ten townships, Twp. 1 to 3 in Rge. 16 to 18, W 1st Mer., part of Twp. 4, Rge. 16, W 1st Mer. and Sec. 6, Twp. 4, Rge. 15, W 1st Mer. (Fig. GS-35-3); it is located on NTS map sheets 62G3, 4, 5 and 6. Provincial highways 3 and 18 bisect the area. The major service centre is the town of Killarney. Provincial Road 346 and gravel section roads give good access to all parts of the municipality. Agriculture is the major source of income in the municipality. As well as grain farms, there are livestock and mixed farms throughout the area.

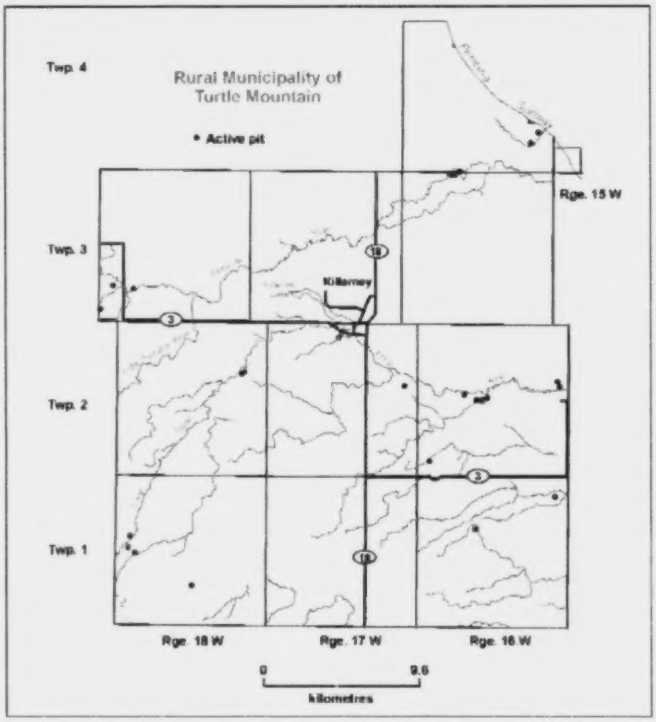


Figure GS-35-3: Rural Municipality of Turtle Mountain showing active pit locations.

While most of the municipality is a gently rolling plain, Turtle Mountain rises to over 650 m asl at the southwestern corner. Several rivers and creeks flow off the mountain and across the plain. The Little Pembina and Pembina rivers flow northeast to the Pembina spillway. Long River flows northeast to Killarney and then turns southeast. Killarney Lake occupies an old watercourse that existed before present-day drainage patterns were established.

Shale and sandstone form the bedrock underlying the municipality. On Turtle Mountain in the southwest corner of the municipality, Tertiary sedimentary rocks of the Turtle Mountain Formation overlie those of the Cretaceous Boissevain Formation. Except for this corner, the uppermost bedrock in the municipality is shale of the Odanah Member of the Cretaceous Pierre Formation (Bamburak, 1978). This is a hard siliceous shale and is commonly found in the gravel deposits in the area. Overburden thicknesses range from 20 to greater than 70 m in the municipality (Sie and Little, 1976); bedrock outcrops are rare but are occasionally present in the banks of river valleys.

The quaternary geology and glacial history of the Killarney–Holmfield area is discussed in Conley (1986). The R.M. of Turtle Mountain forms a small part of this area. The last iceflow to affect the area came from the northwest. Esker deposits, oriented along the direction of iceflow, were deposited at this time. During deglaciation, ice stagnated on Turtle Mountain, while on the plain active ice retreated north to the approximate position of Killarney. Most of the sand and gravel in the municipality was deposited by meltwater finding its way to lower elevations between these two ice masses. Several rivers and creeks carried meltwater from the stagnating ice on the mountain, depositing alluvial fans at the break in slope and as channel or overflow deposits at intermittent locations along their length. Much of the aggregate was deposited in channels that were active for short periods before deeper channels became established. Most of the outwash south of Killarney was deposited this way. The southeast trend of the outwash belt indicates the ice stood at this position during deposition. Further ice retreat caused the abandonment of the Long River channel northwest of Killarney and allowed the Pembina River to flow to the Pembina spillway, at the northeastern edge of the municipality, and for Long River and the creeks south of it to assume their present-day courses.

Aggregate Resources

The methodology for the aggregate inventory in the R.M. of Turtle Mountain was the same as for the R.M. of Ste. Anne. The orthophotos used for compilation were taken in 1995.

There is one shale quarry in the area. The sand and gravel pits are in glaciofluvial deposits scattered across the municipality. Most of the gravel is privately owned and there are only two pits held under quarry lease from the crown. Shale is present in varying quantities in all the deposits. While some percentage of shale is acceptable for most end uses (e.g., 12% for traffic gravel), the specifications for certain products require no shale be present in the aggregate. There is one gravel operator with a shale washing plant in the adjacent municipality of Morton but crushed limestone from near Winnipeg and shale-free aggregate from south of Brandon are imported into the municipality as needed. Ironstone concretions also form part of the deleterious fraction of the gravel.

Deposits

There is one small bedrock quarry located in the side of a meltwater channel in 3-18-W1. The quarry is about 2.5 m deep. The rock is Odanah Member shale that has been fractured and faulted by glacial action.

Only one esker deposit has an active pit. The ridge height varies up to 3.5 m at its highest. The active pit is about 2.5 m deep and is down to till in places. Shale content is moderate and there is a good amount of crushable material in the 5 to 8 cm range.

There are active pits in one alluvial fan deposit, which is located in 1-18-W1. There are two crown and two privately owned pits in the deposit. A portion of the deposit was tested with a backhoe in 1996. The testholes showed that the gravel was deposited over an undulating till surface. Gravel thickness varied from 0.5 to 2.5 m and overlay clay or till. The pits in the rest of the deposit are generally up to 2.5 m deep. Shale content is low to moderate and clasts range up to cobble size (20 cm).

While outwash sediments are found along most of the creeks and along some of the old watercourses, most of the gravel extraction has been from the outwash deposits adjacent to the Pembina and Long rivers. There are numerous old pits and several active pits along the length of these channels. The pits range from 1.5 to greater than 4 m deep, usually expose till in the floor and contain variable amounts of shale and ironstone concretions. The material is generally sandy pebble gravel. Unlike other areas of the province, where outwash deposits often contain a large coarse fraction, cobble- and boulder-size material is a minor component of the deposits. However, most of the deposits contain enough of the 4 to 8 cm fraction to provide adequate material for crushing.

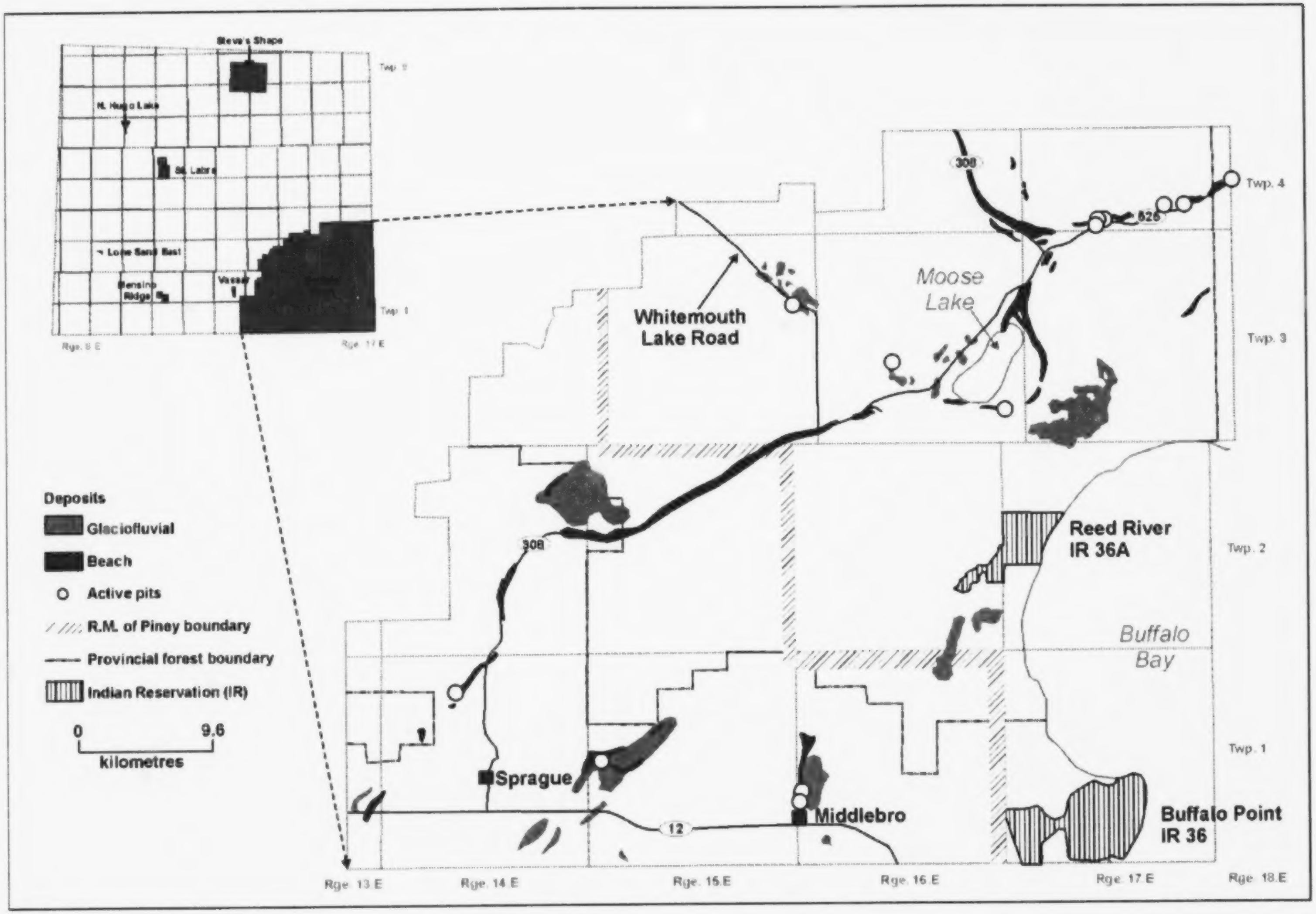

Steve's Shape
N. Hugo Lake
St. Labre
Lone Sand East
Bensino Ridge
Vassar
Twp. 9
Twp. 1
Rge. 8 E
Rge. 17 E
Whitemouth Lake Road
Moose Lake
308
526
Reed River IR 36A
Buffalo Bay
Buffalo Point IR 36
Sprague
Middlebro
12
Twp. 4
Twp. 3
Twp. 2
Twp. 1
Rge. 13 E
Rge. 14 E
Rge. 15 E
Rge. 16 E
Rge. 17 E
Rge. 18 E
Deposits
Glaciofluvial
Beach
Active pits
R.M. of Piney boundary
Provincial forest boundary
Indian Reservation (IR)
0
9.6
kilometres

Figure GS-35-4: Location of ASIs in the study area and aggregate deposits in the Buffalo Point area (after Matile and Thorliefson, 1995).

AREAS OF SPECIAL INTEREST

Areas of Special Interest (ASIs) are parcels of land put forward as candidate sites for study in Manitoba's Protected Areas Initiative. Under this initiative, representative portions of each of Manitoba's natural regions are set aside for biodiversity protection. Mining (including aggregate extraction), forestry and hydro development are excluded activities within areas that proceed to formal protection. **Only** provincially owned lands are considered for the program so that private lands and First Nations lands are excluded unless an agreement is made with the landowners.

Seven candidate areas were assessed this year: Buffalo Point, Steve's Shape, Mensino Ridge and small additions to Vassar, Lone Sand East, North Hugo Lake and St. Labre ASIs. Their locations are given on Figure GS-35-4.

Buffalo Point Area

The Buffalo Point ASI is a large tract of land in southeastern Manitoba. It covers more than twelve townships lying in Twp. 1 to 4, Rge. 13 to 17, E 1st Mer. (Fig. GS-35-4) and is located on NTS sheets 52E3, 4, 5 and 6. Provincial Highway 12 runs through the southern part of the area and Provincial roads 308 and 525 run diagonally across it. Section roads give good access in the southwestern part of the area, but access to the rest of the area is mostly limited to forestry trails. The primary industries are agriculture, forestry and tourism. The Northwest Angle Provincial Forest occupies most of the eastern two-thirds of the area. The Catshills Provincial Forest occupies a small area in 1-14-E1. The R.M. of Piney extends into the area in Twp. 1, Rge. 13 to 16, E 1st Mer., Twp. 2, Rge. 13 to 15, E 1st Mer and Twp. 3, Rge. 14, E 1st Mer. Buffalo Point and Reed River First Nations are located on Buffalo Bay on Lake of the Woods.

The surficial sediments of the area are included on the Whitemouth Lake Area map sheet, at a scale of 1:100 000 (Matile and Thorliefson, 1995). This map is part of the Prairie NATMAP series referenced above in the R.M. of Ste. Anne section. The aggregate resources in the R.M. of Piney were previously mapped at a 1:50 000 scale (Matile, 1994). The late glacial to early postglacial events are the same as those that affected the R.M. of Ste. Anne.

The area is underlain by Precambrian bedrock but overburden thicknesses are generally greater than 15 m (G. Matile and G. Keller, Manitoba Geological Survey, pers. comm., 2002) and there was no bedrock observed during the aggregate survey. Organic deposits form the most widespread surficial unit but there are also large areas of glacial till and littoral sand. The sand and gravel units are outwash plains and beach ridges. As in the Ste. Anne area, the beaches often flank or overlie the outwash deposits (Matile and Thorliefson, 1995).

Aggregate resources

The methodology used for this area was the same as for the R.M. of Ste. Anne and Turtle Mountain. The orthophotos used for compilation were taken in 1997.

There are no bedrock quarries in the area. The gravel deposits are scattered across the area and many have been opened for aggregate extraction. The pebble lithology is primarily carbonate with Precambrian clasts making up the balance of the clasts. There is no shale and a high sand content is the greatest deleterious factor in the deposits. Due to the sparse population, there is little development pressure and most of the aggregate is used for road construction and maintenance. Most of the aggregate resources are crown owned but there are some areas where the gravel is privately held. Most of the private gravel sources are not being mined commercially and it is the crown-owned sources that account for most of the aggregate production.

Deposits

There are only two glaciofluvial deposits that have been mined recently. Aggregate extracted from the deposit near Moose Lake was used to repair the washouts caused by 2002 summer flooding. The other deposit is on the Whitemouth Lake Road. The pits in both of these deposits are up to 2.5 m deep and contain a maximum grain size of 10 cm.

Most of the past aggregate production has been from beach deposits. The main ridges are from 2 to 3.5 m high and usually consist of interbeds of sand, granules and sandy pebble gravel. Grain sizes greater than small cobbles are rare in the sediments. The large ridges often have smaller offshore, bar-type ridges associated with them. These smaller ridges are usually composed of sand with minor amounts of gravel. All of the accessible deposits have pits in them. Most are inactive but some show signs of minor amounts of removal for local use. The only pits currently used for commercial production are those along PR 525.

Along most of their extent, PR 308 and 525 are built on the crests of the largest beach deposits in the area. The deposits were extensively used during construction and there are numerous pits on both sides of the roads. The best remaining aggregate reserves are under the road. A large beach ridge runs north from the town of Middlebro. This deposit was extensively mined in the past and in most places the remaining reserves are sand. However, a recently opened pit at the south end of the ridge shows 2 m of interbedded sand and pebble gravel. Similarly, the deposit in 1-14-E1 has several old pits and a new pit at the south end shows 2.5 m of interbedded sand, granules and fine pebble gravel.

Smaller ASIs

Airphoto interpretation and office compilation showed that the additions to Vassar, St. Labre and North Hugo Lake ASIs are all composed of organic deposits with no aggregate potential. The Lone Sand East addition also has no aggregate within it. Previous mapping of Steve's Shape (Matile, 1991) identified a few small, unopened beach deposits in the northern part and airphoto interpretation showed bedrock outcrops along the eastern edge of the ASI. However, none of these deposits were accessible due to the surrounding organic deposits. Mensino Ridge ASI was mapped and sampled previously (Matile, 1994). One gravel deposit was mapped in the northwestern part of the area. No new pits have been opened in the deposit and the existing pit is inactive. This ASI is in the Sandilands Provincial Forest and the pit is in an area newly planted with trees. Gravel occurs at two locations in the ditches along the northern boundary. The balance of the ASI appears to be sand, much of it blown into dunes.

ACKNOWLEDGMENTS

The author would like to thank G. Munro for field and GIS assistance this summer.

REFERENCES

Bamburak, J.D. 1978: Stratigraphy of the Riding Mountain, Boissevain and Turtle Mountain Formations in the Turtle Mountain area, Manitoba; Manitoba Mines, Resources and Environmental Management, Mineral Resources Division, Geological Report GR 78-2, 47 p.

Conley, G. G. 1986: Surficial geology and stratigraphy of the Killarney–Holmfield area, southwestern Manitoba; MSc thesis, University of Manitoba, Winnipeg, 165 p.

Folk, R.L. 1974: Petrology of Sedimentary Rocks; Hemphill Publishing Company, Austin, 185 p.

Little, J.S. 1980: Winnipeg area (62H); Manitoba Natural Resources, Water Resources, Groundwater availability map series, map at 1:250 000 scale.

Matile, G.L.D. and Conley, G.G. 1979: Quaternary geology and sand and gravel resources of the Rural Municipality of Ste. Anne; Manitoba Energy and Mines, Mineral Resources Division, Map AR80-3, scale 1:50 000.

Matile, G.L.D. 1991: Aggregate resource inventory in the L.G.D. of Reynolds; Manitoba Energy and Mines, Aggregate Report AR89-2, 178 p.

Matile, G.L.D. 1994: Aggregate resource inventory in the Local Government District of Piney; Manitoba Energy and Mines, Aggregate Report AR94-2, 122 p.

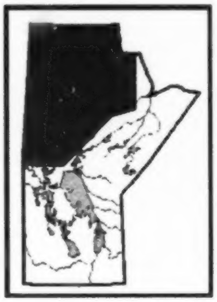
Matile, G.L.D. and Thorliefson, L.H. 1995: Surficial geology, Whitemouth Lake area, Manitoba, Ontario and Minnesota; Manitoba Energy and Mines, Geological Services, Open File Report OFR 95-1, map at 1:100 000 scale.

Matile, G.L.D. and Thorliefson, L.H. 1996: Surficial geology, Steinbach area, Manitoba; Geological Survey of Canada, Open File Report GS OFR 3270, map at 1:100 000 scale.

Sie, D. and Little, J. 1976: Brandon area (62G); Manitoba Natural Resources, Water Resources, groundwater availability map series, map at 1:250 000 scale.

GS-36 SCOPING STUDY FOR HYDROTHERMAL IRON-OXIDE COPPER-GOLD DEPOSITS (OLYMPIC DAM–TYPE), MANITOBA

by A.H. Mumin[1]



Mumin, A.H. 2002: Scoping study for hydrothermal iron-oxide copper-gold deposits (Olympic Dam–type), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 303-308.

SUMMARY

A preliminary scoping study was undertaken to assess the geological potential of Manitoba to host hydrothermal iron-oxide copper-gold (IOCG- or Olympic Dam–type) deposits. At the outset of this project, there were no known examples of IOCG-type deposits in the province, nor has there been any recorded exploration for these deposits. To date, a review and compilation of regional geological and geophysical data has been completed and approximately 87 targets identified for further investigation. Preliminary fieldwork was carried out, including a regional overview and reconnaissance visits to several of the priority targets. Reconnaissance fieldwork confirms the presence of widespread alkali±Fe and other related metasomatic effects associated with late intrusive bodies and large structural lineaments. However, the most important finding to date resulting from this initiative is the discovery of a large, mineralized, carbonatite complex near Eden Lake (Mumin, GS-21, this volume). The scoping study is still in the very early stages, so this article reports only on preliminary investigations and observations, and outlines the intended direction for continued work.

INTRODUCTION

Hydrothermal iron-oxide copper-gold (IOCG-type) deposits are attractive targets for modern exploration and development. They are typically polymetallic, with one or more economic metals that may include various combinations of Fe, Cu, Au, Ag, U, Th, F, Co, Bi, W, rare earth elements (REE) and other metals. The size of deposits varies up to 2 billion tonnes. Examples include the following deposits (Frietsch et al., 1979; Reeve et al., 1990; Hitzman et al., 1992; Smith and Chengyu, 2000):

- Olympic Dam in Australia (2 billion tonnes grading 1.6% Cu, 0.5 g/t Au, 3.5 g/t Ag and 0.6 kg/t U_3O_8)
- Kiruna in Sweden (2–3 billion tones grading 60% Fe)
- Bayan Obo in China (48–100 million tones grading approx. 6% REE oxides).

These deposits are found along modern and ancient continental margins, including extensional and collisional, mature and incipient environments. Most known deposits are Proterozoic, although Phanerozoic and Archean examples occur in many regions of the world. The deposits form from hydrothermal fluids associated with alkali-rich, felsic to intermediate intrusions. They are situated within and marginal to these intrusions, and may occur in any type of host rock (Hitzman et al., 1992; Hitzman, 2000).

This study was undertaken in Manitoba following consultations with staff at the Manitoba Geological Survey. The basic characteristics of IOCG-type deposits were reviewed and considered in the context of the geology of the province, and it was determined that a scoping study should be carried out.

METHOD OF INVESTIGATION

Prospective regions of Manitoba were selected, on the basis of known and suspected tectonic environments, to encompass those areas that were former continental margins, either mature or incipient. Attention was also paid to the presence or possibility of late felsic to intermediate intrusions. The IOCG deposits occur along and at the intersections of major structural lineaments, and this is one of the important exploration guides. The areas of Manitoba that are known and potential continental margins, and were therefore targeted for the initial scoping study, fall within the Trans-Hudson Orogen and include the Churchill-Superior Boundary Zone (including the TNB), the Kisseynew Domain, the Lynn Lake–Leaf Rapids Domain, the Southern Indian Domain, the Chipewyan Domain, the Seal River Domain and the Great Island Domain.

Most IOCG deposits are characterized by large iron and alkali±uranium-thorium enrichments within the host rocks. Consequently, they can be targeted by the presence of coincident magnetic and potassium±uranium-thorium radiometric signatures. Although effective for some potassium- and magnetite-rich systems, this approach will not recognize IOCG deposits characterized by high hematite and/or sodium enrichment. Also, the radiometric signatures are easily masked by water and/or overburden greater than 1 m in thickness. Cultural factors can cause spurious radiometric potassium anomalies and many are due to primary igneous rocks; however, hydrothermal potassium enrichments can be distinguished from natural igneous enrichments by their low radiometric thorium/potassium ratios.

---

[1] Department of Geology, Brandon University, Brandon, Manitoba R7A 6A9

To date, regional radiometric and airborne magnetic survey data have been reviewed for approximately 70% of the target region, in order to locate areas with coincident radiometric and magnetic anomalies. The anomalous areas were further discriminated on the basis of their regional geological setting, and the presence or possible presence of late felsic to intermediate, preferably alkali-rich intrusions. Of particular interest are 'out of place' geophysical anomalies associated with the late intrusions, and any evidence of alkali-iron metasomatism. Approximately 87 target anomalies have been identified, and these were subsequently prioritized into first-, second-, third- and fourth-priority targets for follow up fieldwork and study. Several of the 19 first-priority targets were further researched in the literature and assessment files in preparation for field examination.

PRELIMINARY FIELD INVESTIGATIONS

During June of 2002, preliminary reconnaissance fieldwork was conducted over the Thompson Nickel Belt and an east-west corridor extending from Assean Lake in the east to west of Lynn Lake. Regional rocks in these areas were examined for evidence of IOCG-type hydrothermal and magmatic features. Additionally, specific targets were examined at the Nichols dome and Burntwood River intrusion along the Thompson Nickel Belt, the Wapisu anomaly in the Kisseynew Gneiss Belt, the Eden Lake Alkaline Complex, and part of the region between Eden Lake and the Churchill River.

Churchill-Superior Boundary Zone (Thompson Nickel Belt)

The Thompson Nickel Belt (TNB) is a complex continental terrain boundary with both compressional and extensional phases of deformation. It hosts a number of late felsic to intermediate intrusions. Abundant iron formations are of further interest, and these were examined for evidence of hydrothermal modification related to late igneous activity. The belt was reviewed on a reconnaissance basis from the Williams Lake pluton, beneath the Paleozoic cover in the south, to the Burntwood River granodiorite intrusion, which extends from the town of Thompson northeast for approximately 26 km. Both drill core and surface exposures were examined.

Many but not all rocks of the Thompson Nickel Belt are eroded to levels too deep to be considered highly prospective for IOCG-type deposits. No clear evidence of igneous-associated hydrothermal activity was found in or adjacent to the intrusions that were examined, in other country rocks surrounding these intrusions, or in spatially associated iron formation units. However, the amount of terrain that was examined during the present reconnaissance was quite limited. Felsic pegmatitic segregations associated with partial melting of TNB rocks, particularly pelitic and semipelitic sedimentary rocks, are widespread and form abundant alkali-rich material with minor iron oxides. These melt segregations may have suitable chemistries for the generation of alkali-iron–rich intrusions, if they had been able to accumulate in large masses. One exception that remains of interest is the Burntwood River granodiorite intrusion.

Thompson – Assean Lake

East of the TNB, the most significant features observed to date with possible implications for IOCG deposits were in rare exposures of the Boundary Cataclastic Belt (Fig. GS-36-1). Evidence of widespread hydrothermal potassic and chloritic alteration is present in the brittle deformed rocks. The structurally high-level cataclastic rocks in a major deformation zone, widespread medium-temperature hydrothermal alteration, and evidence for late intrusions with iron metasomatism present a possible scenario for IOCG-type deposits.

Thompson – Lynn Lake

Extending from west of Thompson to Lynn Lake, sedimentary and igneous rocks of the Kisseynew Gneiss Belt were found to be episodically potassium±iron metasomatized to varying degrees. Sulphide-enriched zones and gossans are relatively common, and some of these are proximal to late felsic intrusions. The mineralization is primarily pyrrhotite and/or pyrite, with trace to minor chalcopyrite. In some instances, the sulphide mineralization is associated with weak oxide and silicate facies iron formation. However, most of the sulphide mineralization is situated in crosscutting structures (Fig. GS-36-2). The relationship of this type of mineralization to the abundance of late felsic intrusions in the Kisseynew Belt remains a key question in the context of the present IOCG scoping study.

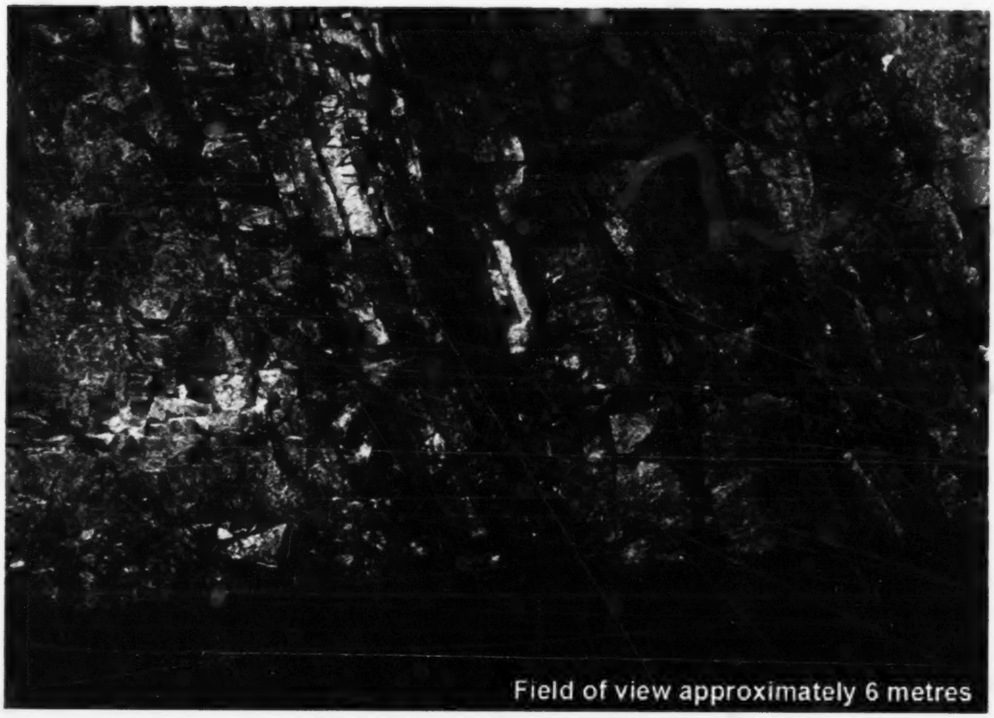

Field of view approximately 6 metres

Figure GS-36-1: Brittle deformed rocks with potassic and chloritic alteration, along with minor hematite and epidote, exposed in a quarry west of Assean Lake.

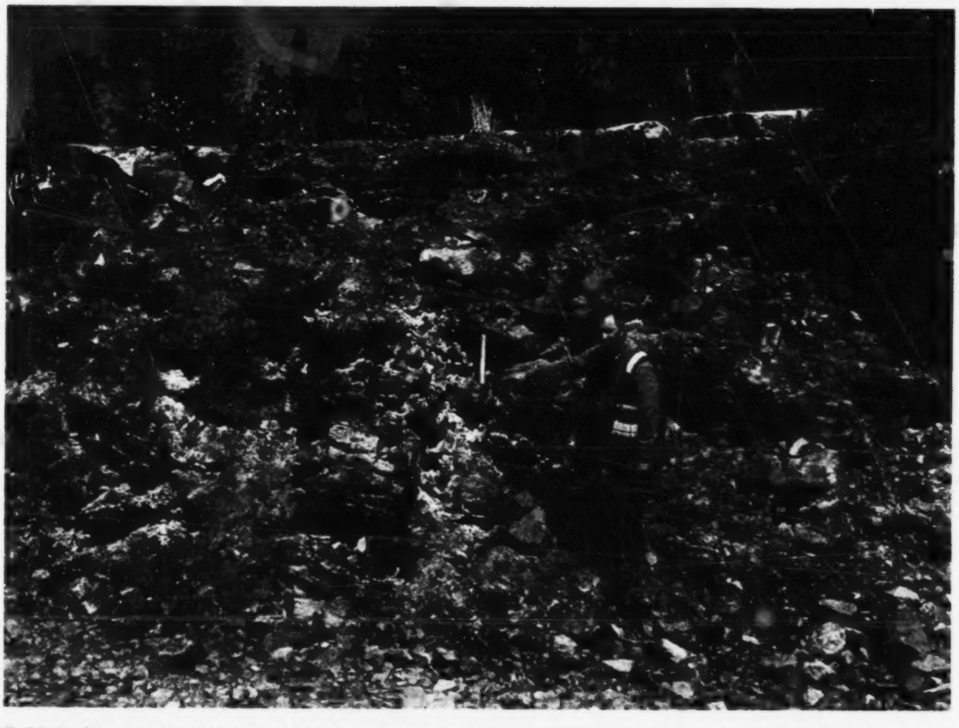


Figure GS-36-2: Abundant sulphide mineralization in structures disrupting Kisseynew metasedimentary rocks, roadcut along the Thompson–Nelson House corridor.

Wapisu anomaly

The Wapisu anomaly consists of strong, coincident, radiometric potassium and magnetic anomalies associated with a late felsic intrusion into Kisseynew metasedimentary rocks. The source of the anomaly was found to be potassic porphyroblastic granodiorite where it intrudes and encompasses lensoid bodies of magnetite-bearing rocks, possibly metasedimentary rocks (Fig. GS-36-3). It is not presently known whether the magnetite in these rocks is primary, hydrothermal or metamorphic in origin. No other evidence of mineralization was observed; however, only a very small portion of the potential zone of interest was visited in the current program.

Eden Lake

The eastern shore of the Eden Lake area was selected as a first-priority target due to the presence of adjacent radiometric potassium and magnetic anomalies, previously reported rare earth element (REE) showings, anomalous uranium signatures, and associated late aegirine-augite–bearing syenite and monzonite (Cameron,1988; McRitchie, 1989; Young and McRitchie, 990; Fedikow et al., 1993; Gunter et al., 1995). Regional reconnaissance carried out over an area between the southeastern shore of Eden Lake and the Churchill River was followed up with a five-week program of detailed mapping and sampling. The present investigations revealed a large hydrothermal and magmatic stockwork and breccia complex with widespread REE enrichments (Fig. GS-36-4). The detailed work resulted in the discovery of several small but well-mineralized carbonatite dikes and plugs within a very large (greater than 7 km^2) carbonatite complex. Rare earth element mineralization occurs in a variety of altered hostrocks and veins. The discovery and nature of the carbonatite complex are presented in a separate paper (Mumin, GS-21, this volume).

CONCLUSIONS

Results from the preliminary stages of this investigation are very encouraging, even though only a small fraction of the target zones has been visited. Evidence of mineralization and/or hydrothermal alteration related to late intrusions and major structures is widespread.

The most important finding to date is the discovery of the mineralized carbonatite complex at Eden Lake. Considering that Eden Lake was selected as a priority IOCG target and a carbonatite complex was discovered, this

Figure GS-36-3: Porphyroblastic, magnetite-bearing rocks occur as lenses and thin sheets in potassic, porphyroblastic granodiorite, 2 km west of the hwest tip of Wapisu Lake.

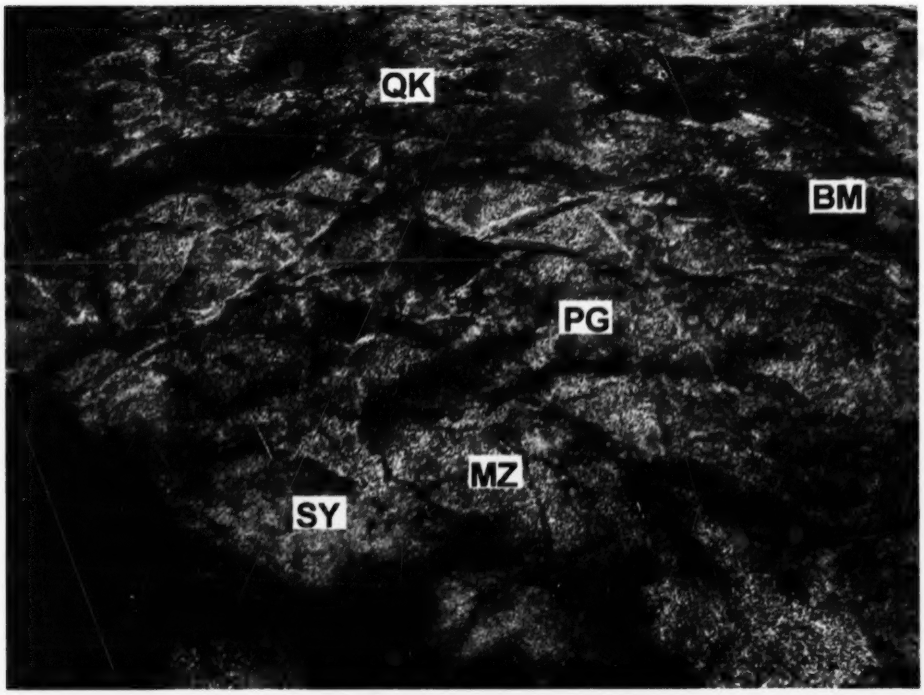


Figure GS-36-4: Small portion of the extensive stockwork and breccia the characterize much of the Eden Lake carbonatite complex, East grid. Narrow syenite veins intrude and disaggregate aegirine-augite–altered monzonite. Abbreviations: BM, blocky mafic breccia; MZ, monzonite; PG, paragneiss; QK, quartz plus K-feldspar pegmatite; SY, syenite.

raises the very intriguing question of the relationship between IOCG (Olympic Dam–type) deposits and carbonatite complexes. This interesting relationship has also been noted and discussed by several other investigators in recent years. The world's largest source of rare earth metals is Bayan Obo in China, which is consistently classified as an IOCG-type deposit. However, some investigators (Zhou et al., 1980; Mariano, 1989; Smith and Chengyu, 2000) consider that the source of mineralization at Bayan Obo may be unexposed carbonatite. Another good example is the Phalaborwa carbonatite complex in South Africa (Africa's largest copper mine), which has recently been discussed in terms of its similarities to, and possible genetic relationship with, IOCG-type deposits (Vielreicher et al, 2000; Harmer, 2000). Equally intriguing is the well-known and documented genetic and spatial relationship of carbonatite complexes with kimberlites. They are generally intergrown or proximally situated. This is an area of ongoing investigation at Eden Lake.

RECOMMENDATIONS AND FUTURE WORK

Most of the priority targets generated during the regional overviews have not yet been examined in the field. A continued program of reconnaissance mapping and sampling is planned in order to examine the remaining priority targets, and to follow up the reconnaissance with more detailed work where warranted. Whole-rock and trace-element geochemistry and petrographic examinations are planned for the more promising targets.

ACKNOWLEDGMENTS

The author is grateful for the consultations and assistance provided by many members of the Manitoba Geological Survey (MGS), and to MGS for funding this project. Inco Technical Services Limited granted access to their property and drill core, and several staff members offered generous assistance and advice. Falconbridge Limited granted access to their drill core. Rare Earth Metals Corp. assisted with some of the reconnaissance at Eden Lake, and funded the subsequent detailed work. Shea Martindale worked diligently on the regional geophysical survey and geology overviews and compilations. John Camier was an invaluable partner in carrying out the fieldwork. This project was funded in part by an NSERC research grant to the author.

REFERENCES

Cameron, H.D.M. 1988: Geology of the Eden Lake area; Manitoba Energy and Mines, Geological Services Branch, Geological Report GR84-2, 18 p.

Fedikow, M.A., Dunn, C.E. and Kowalyk, E. 1993: A vegetation geochemical and radiometric study of a part of the Eden Lake aegirine-augite syenite, northwestern Manitoba (NTS 64C/9); *in* Report of Activities 1993, Manitoba Energy and Mines, Geological Services, p. 5–10.

Frietsch, R., Papunen, H. and Vokes, F.M. 1979: The ore deposits of Finland, Norway and Sweden – a review; Economic Geology, v. 74, p. 975–1001.

Gunter, R., Fedikow, M.A.F., McRitchie, W.D. and Kowalyk, E. 1995: The Eden Lake rare earth element occurrence – metallurgy, geochemical and ground scintillometer surveys (NTS 64C/9), *in* Report of Activities 1995, Manitoba Energy and Mines, Geological Services, p. 11–16.

Harmer, R.E. 2000: Mineralisation of the Phalaborwa Complex and the carbonatite connection in iron oxide-Cu-Au-U-REE deposits; *in* Hydrothermal Iron Oxide Copper-Gold and Related Deposits, A Global Perspective, Australian Mineral Foundation, p. 331–340.

Hitzman, M.W. 2000: Iron oxide-Cu-Au deposits: what, where, when, and why; *in* Hydrothermal Iron Oxide Copper-Gold and Related Deposits, A Global Perspective, Australian Mineral Foundation, p. 9–25.

Hitzman, M.W., Oreskes, N. and Einaudi, M.T. 1992: Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu-U-Au-REE) deposits; Precambrian Research, v. 58, p. 241–287.

Mariano, A.N. 1989: Economic geology of rare earth elements; Reviews in Mineralogy, v. 21, p. 309–337.

McRitchie, W.D. 1989: Ground scintillometer reconnaissance of the Eden Lake aegirine-augite monzonites; *in* Report of Activities 1989, Manitoba Energy and Mines, Geological Services, p. 7–12.

Reeve, J.S., Cross, K.C., Smith, R.N. and Oreskes, N. 1990: Olympic Dam copper-uranium-gold-silver deposit; *in* Geology of the Mineral Deposits of Australia and Papua New Guinea, F.E. Hughes (ed.), Australasian Institute of Mining and Metallurgy, Monograph No. 14, p. 1009–1035.

Smith, M. and Chengyu, W. 2000: The geology and genesis of the Bayan Obo Fe-REE-Nb deposit: a review; *in* Hydrothermal Iron Oxide Copper-Gold and Related Deposits, A Global Perspective, Australian Mineral Foundation, p. 271–281.

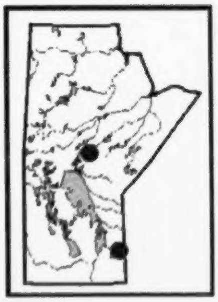
Vielreicher, N.M., Groves, D.I. and Vielreicher, R.M. 2000: The Phalaborwa (Palabora) deposit and its potential connection to iron-oxide copper-gold deposits of Olympic Dam type; *in* Hydrothermal Iron Oxide Copper-Gold and Related Deposits, A Global Perspective, Australian Mineral Foundation, p. 321–329.

Young, J. and McRitchie, W.D. 1990: REE investigations, Eden Lake intrusive suite (NTS 64C/9); *in* Report of Activities 1990, Manitoba Energy and Mines, Geological Services, p. 9–19.

Zhou, Z., Gongyuan, L., Tongyun, S. and Yunguan, L. 1980. On the geological characteristics and the genesis of the dolomitic carbonates at Bayan Obo, Inner Mongolia; Geological Reviews, v. 26, p. 35–42.

GS-37 INDUSTRIAL MINERAL POTENTIAL OF MAFIC-ULTRAMAFIC INTRUSIONS IN MANITOBA

by P.D. Leskiw



Leskiw, P.D. 2002: Industrial mineral potential of mafic-ultramafic intrusions in Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 309.

SUMMARY

In 2001, a documentation of all mafic-ultramafic intrusions in Manitoba was started in an effort to determine the potential for their use as various industrial minerals. Two summer students had previously compiled a bibliography of various sources in an effort to retrieve and store information on some of the industrial mineral commodities. This current documentation will focus on commodities such as chromite, titanium, dimension stone and platinum-group elements in the Bird River, Cross Lake, Red Cross Lake, Pipestone Lake and Kiskitto Lake areas.

INTRODUCTION

Relevant investigations outlining the geology and mineral occurrences in the Bird River greenstone belt, Cross Lake, Red Cross Lake, Pipestone Lake and Kiskitto Lake areas include government reports and maps, graduate research projects, assessment data, published and unpublished papers, journals and company annual reports and press releases. Using these sources of information, an outline of each of the industrial mineral commodities will be provided. Each outline will include the following sections: introduction; geological setting; resource definition; mining methods; tonnage/grade; estimated life expectancy of each deposit; beneficiation methods; specifications and uses; and conclusions. This work will be compiled in an open file report to present an overview for these industrial mineral commodities. Release of this open file report is targeted for March 2003.

GS-38

MANITOBA MINERAL INVENTORY

by J.J. Johnson[1], L. Janower and J.D. Bamburak

Johnson, J.J., Janower, L. and Bamburak, J.D. 2002: Manitoba Mineral Inventory; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 310-311.

SUMMARY

The Manitoba Mineral Inventory (MMI) is an indexed group of hard copy cards and computer files maintained by the Manitoba Geological Survey. These cards and files contain information on the majority of known mineral deposits in Manitoba. The Inventory was started in 1973 after the Mineral Resources Division recognized the need to have an in-house inventory of Manitoba's mineral resources. As the 30th anniversary of inception approaches, the inventory is becoming increasingly out of date. The 2002–2003 updating program began with the goal of updating the entire inventory and increasing accessibility by bringing it onto the Internet.

INTRODUCTION

The MMI was initiated by J. Bamburak in 1973 (Bamburak, 1980). Each Mineral Inventory card consists of specific information relating to a deposit. This includes the location, a geological description of the deposit, a compilation of all exploration and development history, any associated minerals, a history of production (if applicable) and a comprehensive list of references. Hard copies of the Mineral Inventory cards are stored by the Manitoba Geological Survey within a manual file system along with any other information pertinent to the deposit.

Computerization of inventory cards began in 1978. The Inventory has been updated sporadically since 1973 (Bamburak, 1985; Bamburak et al., 1986, 1987, 1988, 1989; Athayde, 1990, 1991a–e). New deposits have been added, but only a few of the old cards have been updated. In 2002, the inventory consisted of 1042 cards, of which approximately 800 have been converted to digital files (Microsoft Word). The majority of these cards have not been updated with new information since the late 1970s or early 1980s.

2002–2003 UPDATING PROJECT

Updating the Inventory

Updating of the inventory began in the late summer of 2001.Fifteen cards from NTS 52E11 (Falcon Lake area) were updated with 2001 data and a new inventory index was created. Due to budget considerations, the updating project was postponed.

The updating of the inventory resumed in 2002. Seventy cards were updated during this time, 10 new cards were created for recently discovered deposits (such as HudBay's 777 deposit in Flin Flon), and 75 cards were converted from paper copies to Microsoft Word documents. The majority of cards updated or added during this season were located in NTS 63K (Flin Flon–Snow Lake area) and 64C (Lynn Lake area). The updated Microsoft Word documents now include scanned images of geological maps, cross-sections, aerial photographs and any other pictorial information that was included in the original paper files.

On-line Inventory

In the past, the Mineral Inventory cards were available in paper format from the library or on microfiche from publication sales. The Mineral Resources Library has now designed a database for the Mineral Inventory cards.

The new Mineral Inventory cards database provides full text search capabilities and is accessible from the Mineral Resources Division web site by clicking on the GIS Map Gallery & Other Databases icon or directly at: http://www.gov.mb.ca/itm/mrd/geo/gis/databases.html

GIS Map Gallery & Other Databases
New & Improved

The database contains over 700 cards and is a work-in-progress as more cards are added and updated. The cards are searchable by keyword or individual field and contain some or all of the following mineral occurrence information:

- Mineral Inventory File Number or Product;
- NTS area or Reference Number;
- Name of Property Owner or Operator and Address;

---

[1] Department of Geological Sciences, University of Manitoba, Winnipeg, Manitoba, R3T 2N2

- Location, Latitude, Longitude, UTM, Township and Range;
- Description of Deposit;
- History of Exploration and Development and/or History of Production;
- Associated Minerals or Products of Value;
- References, Map References, or Remarks.

To obtain more information, to provide feedback on the project, or to notify us of database errors, please contact Jim Bamburak, Industrial Minerals Geologist, Manitoba Geological Survey, Manitoba Industry, Trade and Mines, at jbamburak@gov.mb.ca.

Plans for the Inventory

Within the next year the authors intend to:

- complete updating the files;
- bring the complete inventory on-line; and
- add deposit locations to an on-line GIS map.

ACKNOWLEDGMENTS

Manitoba Government STEP Services is gratefully thanked for providing funding for J. Johnson's employment with the MGS under their CareerOptions program.

The authors would like to acknowledge L. Chudy, K. Proutt and J. Jones for their work on upgrading previously computerized inventory files (in various formats) into Microsoft Word documents.

REFERENCES

Athayde, P. 1990: Manitoba Mineral Inventory; *in* Report of Activities 1990, Manitoba Energy and Mines, Minerals Division, p. 161.

Athayde, P. 1991a: Mineral Inventory Cards (supplement to Economic Geology Report ER79-6): Flin Flon–Snow Lake, NTS 63K/9 to 63K/15; Manitoba Energy and Mines, Miscellaneous Publication 91-2, Part A, 1 v. (various pagings).

Athayde, P. 1991b: Mineral Inventory Cards (supplement to Economic Geology Report ER79-6): Lynn Lake, NTS 64 C/10, 64 C/11 and 64C/12; Manitoba Energy and Mines, Miscellaneous Publication 91-2, Part B, 1 v. (various pagings).

Athayde, P. 1991c: Mineral Inventory Cards (supplement to Economic Geology Report ER79-6): Island Lake, NTS 53 E/9 to 53 E/16 and 53F; Manitoba Energy and Mines, Miscellaneous Publication 91-2, Part C, 1 v. (various pagings).

Athayde, P. 1991d: Mineral Inventory Cards (supplement to Economic Geology Report ER79-6): Pegmatites (Li, Cs, Ta, Be, Sn, W); Manitoba Energy and Mines, Miscellaneous Publication 91-2, Part D, 1 v. (various pagings).

Athayde, P. 1991e: Manitoba Mineral Inventory; *in* Report of Activities 1991, Manitoba Energy and Mines, Minerals Division, p. 96.

Bamburak, J.D. 1980: Mineral Inventory of Manitoba; Manitoba Energy and Mines, Mineral Resources Division, Economic Geology Report ER79-6, 41 p.

Bamburak, J.D. 1985: Compilation, promotion and exploration services (MDS Project 5.9); *in* Report of Field Activities 1985, Manitoba Energy and Mines, Geological Services/Mines Branch, p. 241.

Bamburak, J.D., Richardson, D.J and Leskiw, P.D. 1986: Compilation, promotion and exploration services; *in* Report of Field Activities 1986, Manitoba Energy and Mines, Minerals Division, p. 217.

Bamburak, J.D., Richardson, D.J and Chakowsky, L.E. 1987: Compilation, promotion and exploration services; *in* Report of Field Activities 1987, Manitoba Energy and Mines, Minerals Division, p. 186.

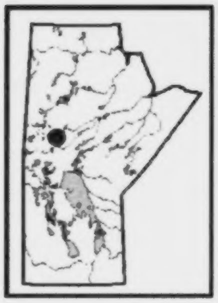
Bamburak, J.D., Chakowsky, L.E. and Athayde, P. 1988: Compilation, promotion and exploration services; *in* Report of Field Activities 1988, Manitoba Energy and Mines, Minerals Division, p. 191.

Bamburak, J.D., Chakowsky, L.E. and Athayde, P. 1989: Compilation, promotion and exploration services *in* Report of Field Activities 1989, Manitoba Energy and Mines, Minerals Division, p. 162.

GS-39

MANITOBA'S PRECAMBRIAN DRILL CORE LIBRARIES PROGRAM: AN UPDATE

by D.E. Prouse



Prouse, D.E. 2002: Manitoba's Precambrian drill core libraries program: an update; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 312-314.

SUMMARY

Manitoba's Mineral Resources Division has been storing Precambrian drill core, obtained primarily from exploration drilling, since the early 1970s. Since that time, the Manitoba government has created a substantial repository of drill core at five locations throughout the province. Throughout most of the 1990s, the core libraries were run on a care-and-maintenance basis. In 2001, funding became available to organize drill core additions from recent years and update core library inventories, including the Centennial core storage site.

When Hudson Bay Mining and Smelting Co. Ltd (HBMS) announced the impending closure of the Ruttan copper-zinc mine near Leaf Rapids in October 2001, the Manitoba Geological Survey (MGS) made funds available to archive drill core stored at the Ruttan minesite. Working in conjunction with Hudson Bay Exploration and Development (HBED) and Ruttan mine geological staff, a summer field program was conducted to retrieve and store Ruttan regional exploration drillholes in the MGS Lynn Lake core library.

INTRODUCTION

The Manitoba Mineral Resources Division considers the archiving of exploration drill core to be a valuable data source for use by mineral exploration companies and for research. For this reason, the province has retrieved and stored Precambrian drill core since the early 1970s. The construction of core storage facilities at The Pas (1972), Thompson (1973) and Lynn Lake (1974) provided space that enabled a concerted effort toward the establishment of a comprehensive drill core collection. The acquisition of storage space in Winnipeg in 1980 for drill core from southeastern Manitoba meant that there was a core storage facility for drill core collected and/or donated from all of Manitoba's major greenstone belts.

The Canada-Manitoba Mineral Development Agreement (MDA), which ran from 1984 to 1989, provided funding towards activities that were key to strengthening Manitoba's mineral industry, including Manitoba's Drill Core Libraries Program. During the term of the agreement, $630 000 was spent on capital and operating costs, allowing for expansion of all northern core storage facilities and proper documentation and organization of inventories. Once the expansion projects were completed, the four libraries had a combined storage capacity of approximately 333 000 m of core. Nearly 80 000 m of core were collected and added to the libraries, and about 58 000 m were discarded during the period of the MDA. The libraries contained nearly 180 000 m of core, representing 54% of total capacity, at the end of the MDA in 1989 (Prouse, 1989)

In 1993, the establishment of a Manitoba Geological Survey (formerly Manitoba Geological Services) expediting base at the former Centennial minesite near Flin Flon provided secure outside storage for drill core from the Flin Flon area. Since that time, thousands of metres of drill core have been donated for storage by various companies. In 2001, the drill core holdings at the Centennial site were reorganized and inventoried for the first time. This work is still in progress.

In July 2002, it was estimated that the Department of Industry, Trade and Mines (ITM) Precambrian drill core library facilities contained approximately 252 000 m of core. This figure includes about 20 000 m of Precambrian core stored at the department's Midland rock lab in Winnipeg. This estimate does not include the substantial holdings at the Centennial site.

2002 FIELD PROGRAM

In October 2001, HBMS announced that it would permanently shut down the Ruttan copper-zinc mine near Leaf Rapids in June 2002. Shortly after closure of the Ruttan operation, HBMS intended to proceed with reclamation of the Ruttan minesite. The Ruttan site contains a very large repository of diamond-drill core (Fig. GS-39-1), from both mine development and exploration drilling, as well as regional exploration drilling by HBED and Ruttan's previous owner, Sherritt Gordon Mines Ltd. During the process of reclamation, all surface buildings, including core storage racks and piles, were to be permanently removed.

Realizing the importance of this drill core, MGS worked in conjunction with HBED to develop a plan to retrieve and archive high-priority exploration drillholes at the department's Lynn Lake core library facility. More than

Figure GS-39-1: View of the extensive drill core holdings at the Ruttan minesite, July 2002.

90 regional exploration drillholes were completed by HBED in the Ruttan–South Indian Lake area since 1990, many of them testing Spectrem airborne geophysical targets. Since the Lynn Lake core library has limited storage space remaining, only the more significant regional exploration drillholes could be archived. Drill logs for 91 exploration drillholes were supplied by HBED and reviewed for results. Based on Manitoba's drill core libraries acquisition policies, priority was given to retrieving and archiving representative holes from the three zinc-copper zones at Darrol Lake, south of Ruttan, and Spectrem airborne geophysical targets. Drillholes that tested Spectrem targets were chosen for archiving if

- encouraging base- or precious-metal values were intersected;
- the drill log reported intersecting volcanic rocks similar to Ruttan mine stratigraphy;
- the area of drilling contains extensive overburden cover; or
- the area has a low drilling density.

In total, 38 drillholes, comprising 939 boxes and totalling approximately 5380 m of core, were collected and archived in the Lynn Lake library. These drillholes will remain in confidential viewing status as long as the respective claim on which the drilling was conducted remains in good standing.

At the outset of planning the Ruttan core retrieval and archiving program, it was intended that personnel from the Ruttan geology department and HBED would select and archive a number of drillholes that would adequately represent the Ruttan deposit and area stratigraphy. This has been indefinitely postponed, since HBMS has decided not to reclaim the area containing the drill core. Instead, an earth berm, being constructed to enclose the Ruttan property, will incorporate the drill core storage area. It is hoped that this will aid in deterring vandalism to the drill core.

Other work carried out at Manitoba's core libraries consisted of continued development of an inventory of the core holdings at the Centennial compound near Flin Flon. Approximately 90% of this core has now been inventoried and reorganized. Considerable work remains to be done to acquire the necessary background information for the majority of the Centennial drillholes. At The Pas core library, general building maintenance and inventory updating were completed. In Lynn Lake, personnel from the MGS Midland rock lab successfully stabilized the leaning interior core racks.

HOW TO USE MANITOBA'S CORE LIBRARIES

All five core libraries have lighted, heated inspection rooms with benches, and most have core splitters. Since the core libraries are not permanently manned, enquiries and requests for access to the northern libraries must be made to:

Dave Prouse, Resident Geologist
Manitoba Geological Survey
Manitoba Industry, Trade and Mines
143 Main Street, Suite 201
Flin Flon, MB R8A 1K2
Phone: (204) 687-1632
Email: dprouse@gov.mb.ca

Access to view core at the Brady Road facility in Winnipeg should be arranged with:

Jim Payne, Assessment Geologist
Mines Branch
Manitoba Industry, Trade and Mines
1395 Ellice Avenue, Suite 360
Winnipeg, MB R3G 3P2
Phone: (204) 945-6535
Email: jpayne@gov.mb.ca

Once permission has been granted to view nonconfidential core in a specific library, arrangements will be made for the user to obtain keys to gain access to that facility. In the case of Thompson and Flin Flon, keys can be obtained at the local ITM offices. Keys for access to The Pas and Lynn Lake core libraries will be made available at the local office of Manitoba Conservation.

The master file for drillhole logs, collar locations and assays for nonconfidential drill core holdings in The Pas, Lynn Lake and Flin Flon libraries are available for inspection at the ITM office in Flin Flon. The corresponding files for core stored in the Thompson and Winnipeg libraries are available for viewing at the ITM office in those locations.

Viewing, storage and sampling policy

Access to confidential drill core is allowed only with written permission from the company that holds the property. This information must be presented to the Resident Geologist in Flin Flon or the Assessment Geologist in Winnipeg prior to inspection (depending on the core library in question).

Core boxes placed in a library will be managed by ITM personnel. Removal of core boxes from the library premises is not permitted. Users wishing to examine core must be prepared to physically handle the core boxes and return them to the storage racks. Permission is required to sample core contained in any of the province's libraries. Assay results and pulps from these samples must be forwarded if requested. Quartering of previously sampled drill core is not permitted.

ACKNOWLEDGMENTS

The Ruttan core retrieval program could not have been a success without the knowledgeable support of Reg Yaworski of the HBMS Ruttan mine geology department, and Kelly Gilmore of HBED in Flin Flon. Student assistant Cody Peever is thanked for his hard work in moving Ruttan drill core and for his work at the Centennial and The Pas core libraries. The always dependable logistical support of Neill Brandson of the MGS is gratefully appreciated. Thanks are extended to Doug Berk, Vio Varga and assistants of the MGS Midland rock laboratory for completing the maintenance work on the Lynn Lake core racks.

REFERENCES

Prouse, D.E. 1989: Manitoba's drill core libraries system; Manitoba Energy and Mines, Minerals Division, Open File Report OF89-4, 44 p.

PUBLICATIONS

PRELIMINARY MAPS

PMAP2002-1 Geology of the Lake Aimée–Naosap Lake–Alberts Lake area (parts of NTS 63K13SE and 14SW)
by H.P. Gilbert .... scale 1:20 000
(Supercedes Preliminary Map 1997F-1)

PMAP2002-2 Geology of the western portion of Island Lake (NTS 53E15)
by J. Parks .... scale 1:50 000

PMAP2002-3 Geology of southern Granville Lake (parts of NTS 64C1, 2 and 7)
by H. Zwanzig and H.D.M. Cameron .... scale 1:20 000
(Supercedes Preliminary Map 1981L-2 and 1981L-3)

Manitoba Geological Survey Reports and Maps

Geoscientific Papers

GP2002-1
Kimberlite indicator-mineral survey, lower Hayes River / Nielsen, E., Fedikow, M.A.F.

Open File Reports

OF2001-1
Operation Superior: multimedia geochemical survey results from the northern half of the Knee Lake greenstone belt, northern Superior Province, Manitoba (NTS 53L) / Fedikow, M.A.F. Nielsen, E. Conley, G.G. and Lenton, P.G.

OF2001-2
Enzyme leach^{sm} geochemical profile over the Bil Group (Gods River) lithium pegmatite, Gods Lake area, east-central Manitoba (NTS 53L/16) / Fedikow, M.A.F.

OF2001-3
Kimberlite indicator minerals from west-central Manitoba (NTS 62N, 63C, 63K) / Bamburak, J.D. and Fedikow, M.A.F.

OF2001-5
Operation Superior: kimberlite indicator mineral survey results (2000) for the northern half of the Knee Lake greenstone belt, Manitoba (NTS 53M) / Fedikow, M.A.F., Nielsen, E., Conley, G.G. and Lenton, P.G. (digital web site release)

OF2001-8
Geoscience data compilation for southeastern Manitoba / Panagapko, D.A., Chackowsky, L., Lenton, P., Bailes, A.H., Corkery, M.T., Poulsen, K.H., Brommecker, R., Weber, W., Ames, D.E., Scoates, R.F.J., Garson, D.F., Theyer, P., Percival, J., Thorleifson, L.H., Matile, G.L.D., Grant, N.M., Burt, A.K. and Mann, J.D.

OF2001-9
Geology, alteration mineralogy, geochemistry and volcanogenic massive-sulphide potential of the Ruttan mine area and the southern Rusty Lake volcanic belt (NTS 64B) / Barrie, C.T. and Taylor, C.F.

OF2002-1
Operation Superior: compilation of kimberlite indicator mineral survey results (1996-2001) / Fedikow, M.A.F., Nielsen, E., Conley, G.G. and Lenton, P.G. (digital web site release only)

Report of Activities 2001

Annual review / Syme, E.C., p. 1-7.

Flin Flon – Snow Lake

Flin Flon targeted geoscience initiative / Galley, A.G. and Bailes, A.H., p. 9-17.

Geology of the Wabishkok Lake area (parts of NTS 63K/13NE and /14NW) / Gilbert, H.P., p. 18-27.

Josland Lake sills: U-Pb age and tectonostratigraphic implications (parts of NTS 63K and 63N) / Zwanzig, H.V., Bailes, A.H. and Böhm, Ch.O., p. 28-32.

Platinum-group element investigations in the Flin Flon greenstone belt: McBratney Lake occurrence and Josland Lake intrusion (parts of NTS 63K/9, /13) / Theyer, P., p. 33-39.

Mineral deposit studies in the Flin Flon–Snow Lake area / Gale, G.H., p. 40-44.

Activities of the Flin Flon regional office / Heine, T.H. and Prouse, D.E., p. 45-46.

Thompson Nickel Belt, Superior Boundary Zone, Fox River Belt

Thompson Nickel Belt Project: progress report / Macek, J.J., Zwanzig, H.V. and McGregor, C.R., p. 47-50.

Superior Boundary Zone–Reindeer Zone transition in the Pearson Lake–Odei River–Mystery Lake region (parts of NTS 63P and 64O) / Zwanzig, H.V., Böhm, Ch.O. and Etcheverry, J., p. 51-56.

Hydration of Pikwitonei Domain granulite along the east margin of the Thompson Nickel Belt (part of NTS 63J/16) / Lettley, C.D., p. 57-58.

Pegmatite remagnetization at about 1.7 Ga in the southern Thompson Nickel Belt, from paleomagnetism / Harris, M.J., Symons, D.T.A., Peck, D.C., Blackburn, W.H. and Turek, A., p. 59-66.

Lynn Lake

Structural analysis and investigations of shear-hosted gold mineralization in the southern Lynn Lake greenstone belt (parts of NTS 64C/11, /12, /15, /16) / Beaumont-Smith, C.J., Anderson, S.D. and Böhm, Ch.O., p. 67-75.

Structural analysis of the Pool Lake–Boiley Lake area, Lynn Lake greenstone blt (NTS 64C/11) / Anderson, S.D. and Beaumont-Smith, C.J., p. 76-85.

Stratigraphic and structural mapping of the Agassiz Metallotect near Lynn Lake, Lynn Lake greenstone belt (parts of NTS 64C/14, /15) / Ma, G. and Beaumont-Smith, C.J., p. 86-93.

Preliminary results from the Churchill River–Southern Indian Lake Targeted Geoscience Initiative / Corrigan, D., Therriault, A. and Rayner, N.M., p. 94-107.

Northern Superior

Multimedia geochemical and mineralogical surveys, Northern Knee Lake–Fish Lake greenstone belt, northern Superior Province (NTS 53M/1, 53M/8, 53N/3, 53N/4 and 53N/5) / Fedikow, M.A.F. and Nielsen, E., p.108-110.

Deformation history of the Central Cross Lake Shear Zone, northwestern Superior Province (part of NTS 63I/12) / Dai, T., Jiang, D. and Corkery, M.T., p. 111-114.

Geology and geochronology of the Island Lake greenstone belt, northwestern Superior Province / Parks, J., Lin, S., Corkery, M.T. and Davis, D.W., p. 115-120.

Quaternary stratigraphy, till provenance and kimberlite indicator-mineral surveys along the Lower Hayes River / Nielsen, E., p. 121-125.

Southeastern Manitoba

Stratigraphy, geology and mineralization of selected parts of the Page Property, Bird River Sill (part of NTS 52L/5) / Theyer, P., Bruni, E. and Sundell, C., p. 126-132.

Investigation of Precambrian monadnocks (NTS 62I/1 and 62I/8) / Bezys, R.K., Matile, G.L.D. and Keller, G.R., p. 133-137.

Phytoremediation of mine tailings and bio-ore production: results from a study on plant survival at the Central Manitoba (Au) minesite (NTS 52L/13) / Renault, S., Sailerova, E. and Fedikow, M.A.F., p. 138-149.

Southern Manitoba

Manitoba Stratigraphic Database and the Capital Region Study, 2001 / Conley, G.G., p. 150-151.

Construction of a three-dimensional geological model for the southern Manitoba Phanerozoic terrane / Matile, G.L.D., Thorleifson, L.H., Bamburak, J.D., Bezys, R.K., Nicolas, M.P.B., Conley, G.G., Keller, G.R. and Pyne, M., p. 152-155.

Solution-collapse breccia of the Upper Devonian Sagemace Member, Souris River Formation, Winnipegosis area: Progress Report / Friedrich, L. and Chow, N., p.156-158.

Stratigraphic investigations and corehole drilling program, 2001 / Bezys, R.K. and Bamburak, J.D., p. 159-163.

Gravity and magnetic profile along The Pas Moraine / Surasky, A.T., Hosain, I.T. and Letkemen, A.J., p. 164-171.

Aggregate inventories: Churchill area, Rural Municipality of Grandview and selected Areas of Special Interest / Groom, H.D., p. 172-178.

Manitoba General

Updating Manitoba's Precambrian drill core libraries inventory / Prouse, D.E., p. 179-181.

Geoscience Information Services projects / Lenton, P.G., Chackowsky, L., Pacey, M. and Lindal, D., p. 182-188.

Bedrock Geology Compilation Maps

NTS64O
Munroe Lake, scale 1:250 000

Geoscientific Maps

MAP2002-1
Geology of the Baker Patton Complex, Flin Flon, Manitoba (parts of NTS areas 63K12, 13) / Gale, G.H. and Dabek, L.B., scale 1:10 000

Preliminary Maps

MAP2001F-1
Geology of the Millrock Hill area, Flin Flon (parts of NTS 63K/13SW, /12NW) / Gibson, H.L., Bailes, A.H., Tourigny, G. and Syme, E.C., scale 1:500

MAP2001F-2
Geology of the South Main shaft area, Flin Flon (part of NTS 63K/13SW) / Bailes, A.H., Bray, D. and Syme, E.C., scale 1:500

MAP2001F-3
Geology of the Wabishkok Lake area (parts of NTS 63K/13NE, /14NW) / Gilbert, H.P., scale 1:20 000

MAP2001S-1
Geology of the Fox River sill in the Great Falls area, Fox River belt, northeastern Manitoba (part of NTS 53M/16) / Desharnais, G., Peck, D.C., Potter, L., Huminicki, M., Scoates, R.F.J., Theyer, P., Wegleitner, C., Kohut, G., Smerchanski, P., Benson, D., Petch, C. and DeSchutter, G., scale 1:2500

MAP2001S-2
Geology of the Pipestone Lake area (parts of NTS 63I/5, /12) / Parmenter, A.C., Lin, S. and Corkery, M.T., scale 1:20 000

Manitoba Mining & Minerals Convention Speaker Abstracts
Winnipeg, Manitoba, November 15-17, 2001

Babulic, P. 2001: Birchtree Mine Deepening Project, Manitoba Industry, Trade and Mines; Manitoba Mining & Minerals Convention 2001: program, p. 40.

Bamburak, J. 2001: Moving Manitoba — a slow bumpy crustal ride through geological time; Manitoba Industry; Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 43.

Barrie, C.T. and Taylor, C. 2001: Geological, geochemical, and XRD alteration mineralogical studies in the Ruttan Cu-Zn mine area and the southern Rusty Lake volcanic belt, Manitoba; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 42.

Beaumont-Smith, C., Anderson, S., Ma, G. and Jones, R. 2001: Lynn Lake TGI: structural analysis of the Lynn Lake greenstone belt and investigations into structural controls on gold mineralization; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 43.

Bloodworth, B. 2001: Northern partnerships — the path to the future; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 44.

Corrigan, D. 2001: Lynn Lake TGI: the Southern Indian transect; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 43.

Ettlinger, A. 2001: Canadian diamonds — fascinating from every angle; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 41.

Fedikow, M.A.F. and Lewis, M. Patrick 2001: Soil geochemical exploration techniques: results from the McBratney Lake PGM Project, Flin Flon area, Manitoba; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 46.

Fedikow, M.A.F. and Nielsen, E. 2001: Five years of kimberlite indicator mineral surveys in Manitoba's Northern Superior Province, Operation Superior (1996-2000); Manitoba Industry, Trade and Mines, Manitoba Mining

& Minerals Convention 2001: program, p. 42.

Fedikow, M.A.F. and Nielsen, E. 2001: Multimedia geochemical survey results from the northern half of the Knee Lake greenstone belt, 2000 (Operation Superior); Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 43.

Fowler, J.A. 2001: Working with communities; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 46.

Fraser, W.W. 2001: Designing for closure; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 41.

Galley, A. 2001: Flin Flon Targeted Geoscience Initiative; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 42.

Garrett, R.G., Fedikow, M.A.F., Bamburak, J., Bezys, R. and Keller, G. 2001: Phanerozoic chemostratigraphy — a tale of metal deposition in black shales; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 45.

Green, P. 2001: Tanco Mines 18-J Long Hole Project: change enhanced with experience; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001 program, p. 46.

Macek, J. 2001: Nickel Belt 1:50 000 maps: results of a government and industry partnership; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 44.

McCombe, D. 2001: National Instrument 43-101: standards of disclosure for mineral properties; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 44.

Morao, C. 2001: Hudson Bay's 777 Project; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 43.

Nielsen, E. 2001: Quaternary history of the northern Superior Province: implications for diamond exploration; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 45.

Osadetz, K. 2001: Phanerozoic thermal and tectonic influences on mineralization processes in Manitoba; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 45.

Peck, D.C., MacEachern, D., and Robertson, D.J. 2001: Assessing the potential for PGE deposits in Ni sulphide districts: Falconbridge Limited's Manitoba PGE exploration strategy; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 40.

Percival, J.A., Skulski, T., McNicoll, V., Stern, R., Tomlinson, K., Sanborn-Barrie, M., Whalen, J. Stott, G.M., Corkery, T. and Bailes, A. 2001: Neoarchean assembly of the western Superior Province; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 44.

Skulski, T., Sanborn-Barrie, M., Whalen. J., Percival, J., McNicoll, V., Craven, J., White, D., Corkery, T., Bailes, A., Stone, D., Parker, J. and Calvert, A. 2001: Break-up and make-up of the northwestern Superior Province, Canada; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 41.

Strong, K. 2001: CDNX: The public venture capital market opportunity; Manitoba Industry, Trade and Mines,

Manitoba Mining & Minerals Convention 2001: program, p. 41.

Theyer, P. 2001: Platinum group elements in Manitoba — progress report for 2001; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 45.

Thomas, M. and Pilkington, M. 2001: Geophysical mapping of Precambrian basement in Manitoba; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 42.

Zwanzig, H. 2001: A new interpretation of Thompson Nickel Belt structure with implications for exploration; Manitoba Industry, Trade and Mines, Manitoba Mining & Minerals Convention 2001: program, p. 40.

External Publications

Bamburak, J. D. and Bezys, R.K. 2002: Industrial minerals and Paleozoic geology of southeastern Manitoba; *in* Proceedings Volume 48, Part 2 - field trip guidebook, Institute on Lake Superior Geology, 48th Annual Meeting, Kenora, Ont. May-12-16, 2002, p. 69-94.

Beaumont-Smith, C.J., Böhm, Ch. O, Jones, L.R. and Lafrance, B. 2002: Tectonic assembly of the Lynn Lake greenstone belt and the structural setting of shear-hosted gold mineralization, northern Trans-Hudson Orogen, Manitoba; Geological Association of Canada, Mineralogical Association of Canada, 2002 Joint Annual Meeting, Program with Abstracts, v. 27, p. A7.

Bezys, R.K., Bamburak, J.D., McCabe, H.R. and Kent, D.M. 2002: Lower to Middle Paleozoic stratigraphy of southwestern Manitoba; Nexen field trip guidebook, June 17-20, 2002, 72 p.

Böhm, Ch.O., Heaman, L.M., Creaser, R.A., Corkery, M.T. and Stern, R.A. 2002: Tectonic assembly of the Trans-Hudson–Superior boundary zone in northern Manitoba: from Paleoarchean crustal remnants to Paleoproterozoic collision; GAC-MAC Annual Meeting, Saskatoon 2002, Abstracts Volume 27, p. 11.

Brooks, G.R., St. George, S., Lewis, C.F.M., Medioli, B.E., Nielsen, E.N., Simpson, S. and Thorleifson, L.H. 2001: Geoscientific contributions to understanding flood hazards in the Red River valley, Manitoba [Abstract]; Canadian Water Resources Association Annual Meeting, Winnipeg, Manitoba, June 11-14, 2002.

Brooks. G.R., St. George, S., Lewis, C.F.M., Medioli, B.E., Nielsen, E., Simpson, S. and Thorleifson, L.H. 2002: Geoscientific contributions to understanding flood hazards in the Red River valley, Manitoba; Canadian Water Resources Association Annual Meeting, Winnipeg, Manitoba, June 11-14, 2002.

Buhay, W.M, Blair, D., Nielsen, E., St. George, S. and Brooks, G. 2002: Isotopic records of past hydroclimatic change in the Red River basin, southern Manitoba, Canada; PAGES newsletter 10, p. 9-10.

Burt, A.K., Brennand, T.A., Matile, G.L.D., Keller, G. and Thorleifson, H.L. 2002: Reinterpretation of the Belair Moraine, southeastern Manitoba, Canada, based on a regional digital elevation model and new geological data; Geological Society of America Joint Annual Meeting North-Central Section (36th) and Southeastern Section (51st), Abstracts with Programs, Lexington, April 2002.

Galley, A.G. and Bailes, A.H. 2002: Volcanogenic massive sulphide-related hydrothermal events within the Paleoproterozoic Snow Lake arc assemblage; Field Trip A2 Guidebook, Geological Association of Canada/Mineralogical Association of Canada Annual Meeting, Saskatoon, Saskatchewan, May 27-29, 2002, 94 p.

Galley, A.G., Bailes, A.H., Gibson, H.L, Tourigny, G., Ames, D.A., Devine, C.A., Gale, G., Jonasson, I.R., Mitchinson, D.E., Syme, E.C., Tardif, N.P. and Taylor, B.E. 2001: Preliminary results of the Flin Flon Targeted Geoscinece Initiative, Saskatchewan and Manitoba; Geological Survey of Canada, Current Research 2002-C24, 11 p.

Galley, A.G., Bailes, A.B, Hannington, M., Holk, G., Katsube, J., Paquette, F., Paradis, S., Santaguida, F. and Taylor, B. 2002: Database for CAMIRO Project 94E07: interrelationships between subvolcanic intrusions, large-scale alteration zones and VMS deposits, Ontario, Manitoba, Quebec and Sweden; compiled by B. Hillary, 1 CD-ROM.

Galley, A.G., Bailes, A.H. and Tourigny, G. 2001: GS-a: the Flin Flon Targeted Geoscience Initiative; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 2001-4.2

Grasby, S.E., Gryba, E.M. and Bezys, R.K. 2002: A bedrock source of Swan River chert; Plains Anthropologist, v. 47, no. 182, p. 275-281.

Hiebert, W. and Keller, G. 2002: Digital Elevation Model of southern Manitoba; Cartouche: Newsletter of the Canadian Cartographic Association, Number 46, Summer 2002.

Lewis, C.F.M., Forbes, D.L., Todd, B.J., Nielsen, E., Thorleifson, L.H., Henderson, P.J., McMartin, I., Anderson, T., Betcher, R.N., Buhay, W.M., Burbidge, S.M., Schröder-Adams, C., King, J., Moran, K., Gibson, C., Jarrett, C.A., Kling, H.J., Lockhart, W.L., Last, W.M., Matile, G.L.D., Risberg, J., Rodrigues, C., Telka, A.M. and Vance, R.E. 2001: Uplift-driven expansion delayed by middle Holocene desiccation in Lake Winnipeg, Manitoba, Canada; Geology, 29, no. 8, p. 743-746.

Ma, G., Beaumont-Smith, C.J. and Jones, L.R. 2001: Structural evolution and controls on gold mineralization in the Paleoproterozoic Lynn Lake greenstone belt, northern Manitoba; Geological Association of Canada, Mineralogical Association of Canada, Program with Abstracts, v. 26, p. A90.

Nielsen, E. and Matile, G.M. 2002: Quaternary geology of southeastern Manitoba; *in* Proceedings Volume 48, Part 2 - field trip guidebook, Institute on Lake Superior Geology, 48th Annual Meeting, Kenora, Ont. May 12-16, 2002, p. 23-35.

Nielsen, E., St. George, S., Matile, G. and Keller, G. 2002: Environmental geoscience in the Red River valley; CPG/NGSC field trip guidebook, 2002 Energy and Mines Ministers' Conference, Winnipeg, Manitoba, September 14, 2002.

Peck, D.C.P., Scoates, R.F.J., Theyer, P., Desharnais, G., Hulbert, L.J. and Huminicki, M.A.E. 2002: Stratiform and contact-type mineralization in the Fox River Sill and the Bird River Belt, Manitoba; *in* The Geology, Geochemistry, Mineralogy and Mineral Beneficiation of Platinum-Group Elements, Cabri L.J. (editor), CIM Special Volume 54, p. 367-387.

Percival, J.A., Bailes, A.H. and McNicoll, V. 2001: Mesoarchean western margin of the Superior craton in the Lake Winnipeg area, Manitoba; *in* Geological Survey of Canada, Current Research 2002-C16, 19 p.

Percival, J.A., Bailes, A.H. and McNicoll, V. 2002: Mesoarchean breakup, Neoarchean acrretion in the Western Superior craton, Lake Winnipeg, Canada; Field Trip B3 Guidebook, Geological Association of Canada/Mineralogical Association of Canada Annual Meeting, Saskatoon, Saskatchewan, May 27-29, 2002, 42 p.

Prouse, D.E. 2002: Manitoba exploration and development highlights 2001; Exploration and development highlights: an annual publication of the Prospectors and Developers Association of Canada, p. 8-11.

Prouse, D.E. 2002: Manitoba exploration and development highlights 2002; Canadian Mining Journal, October 2002, p. 23-25.

Rogge, D.M., Beaumont-Smith, C.J. and Halden, N.M. in press: Application of data fusion for structure and deformation potential analysis, Lynn Lake greenstone belt, Manitoba, Canada; Canadian Journal of Remote Sensing.

St. George, S. and Nielsen, E. 2001: Recent hydroclimatic change in the Red River basin inferred from tree rings [Abstract]; Great Plains geomorphology and environmental change; Geological Association of Canada–Mineralogical Association of Canada Joint Meeting, Saskatoon, Saskatchewan, May 27-29, 2002.

St. George, S. and Nielsen, E. 2002: Applications of dendrohydrology to flood hazards in the Red River basin [Abstract]; Sixth International Conference on Dendrochronology, Québec City, Québec, August 22-27, 2002.

St. George, S. and Nielsen, E. 2002: Southern Manitoba annual precipitation reconstruction; International Tree-Ring Data Bank; IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #2002-060. NOAA/NGDC Paleoclimatology Program, Boulder, CO, USA.

St. George, S. and Nielsen, E. in press: Paleoflood records for the Red River, Manitoba, Canada derived from anatomical tree-ring signatures; The Holocene 13.

St. George, S. and Nielsen, E. in press: Hydroclimatic change in southern Manitoba since AD 1409 inferred from tree rings; Quaternary Research.

St. George, S., Nielsen, E., Conciatori, F. and Tardif, J. in press: Trends in Quercus macrocarpa vessel areas and their implications for tree-ring paleoflood studies; Tree-Ring Research.

St. George, S., Nielsen, E. and Ferguson, G. 2002: Paleoenvironmental evidence for hydroclimatic change and extreme flooding in the Red River basin over the last 700 years [Poster and Abstract]; Canadian Water Resources

Association Annual Meeting, Winnipeg, Manitoba, June 11-14, 2002.

Thorleifson, L.H., Matile, G.L.D., Keller, G.R. and Pyne, D.M. 2001: Development of protocols for 3D geological modelling in support of regional groundwater applications in the Winnipeg/Lake Winnipeg region, Canada; Geological Society of America Annual Meeting, Boston, October 2001, Abstracts with Programs, v. 33, no. 6, 2001 GSA Annual Meeting, Boston, p. A-268.

White, D.J., Lucas, S.B., Bleeker W. and Corrigan, D. 2002: Comparison of the collisional margins of the Trans-Hudson Orogen; Geological Association of Canada, Mineralogical Association of Canada, GAC/MAC annual meeting, Saskatoon, SK, May 27–29, (Abstract), v. 27, p. 123.

White, D.J., Lucas, S.B., Bleeker, W., Hajnal, Z., Lewry, J.F., Zwanzig, H.V. 2002: Suture-zone geometry along an irregular Paleoproterozoic margin: the Superior boundary zone, Manitoba, Canada; Geology, v. 30, no. 8, p. 735–738.

Zwanzig, H.V. and White, D. J. 2002: Crustal architecture and evolution of collisional zones in Trans-Hudson Orogen, Manitoba: no easy answers; Geological Association of Canada, Mineralogical Association of Canada, GAC/MAC annual meeting, Saskatoon, SK, May 27-29, (Abstract), v. 27, p. 132.

MANITOBA GEOLOGICAL SURVEY

Position	Personnel	E-mail	Phone (*Area Code 204*)	Areas of interest
Director	Ric Syme	rsyme@gov.mb.ca	945-6556	
PRECAMBRIAN MAPPING SECTION				
Chief Geologist	Dr. Alan Bailes	abailes@gov.mb.ca	945-6555	Flin Flon Belt, SE Manitoba
Partnerships Coordinator	Tim Corkery	tcorkery@gov.mb.ca	945-6554	Superior Province, SE Manitoba, Superior Boundary Zone
Geologist	Paul Gilbert	pgilbert@gov.mb.ca	945-6547	Flin Flon Belt, N Superior Province
Geologist	Cathy McGregor	cmcgregor@gov.mb.ca	945-6543	Thompson Nickel Belt
Geologist	Dr. Josef Macek	jmacek@gov.mb.ca	945-6548	Thompson Nickel Belt
Geologist	Dr. Herman Zwanzig	hzwanzig@gov.mb.ca	945-6552	Superior Boundary Zone; Lynn Lake Belt
MINERAL DEPOSITS SECTION				
Chief Geologist	Vacant (A.H. Bailes, Acting)			
Regional geologist, Thompson	Dr. Scott Anderson	scanderson@gov.mb.ca	677-6886	Lynn Lake Belt, Rusty Lake Belt, SE Manitoba
Mineral deposit geologist	Chris Beaumont-Smith	cbeaumont@gov.mb.ca	945-6566	Lynn Lake Belt; Rusty Lake Belt, SE Manitoba
Mineral deposits database geologist	Malcolm Cameron	malcameron@gov.mb.ca	677-6562	Superior Province
Mineral deposit geologist	Dr. George Gale	ggale@gov.mb.ca	945-6561	Flin Flon Belt, Rusty Lake Belt, Lynn Lake Belt
Regional geologist, Flin Flon	Tom Heine	theine@gov.mb.ca	687-1633	Flin Flon Belt
Resident geologist, Flin Flon	Dave Prouse	dprouse@gov.mb.ca	687-1632	Core libraries
Mineral deposit geologist	Dr. Peter Theyer	ptheyer@gov.mb.ca	945-6545	Thompson Nickel Belt, SE Manitoba, Flin Flon Belt
SEDIMENTARY AND INDUSTRIAL MINERALS SECTION				
Chief Geologist	Ruth Bezys	rbezys@gov.mb.ca	945-6563	Southern Manitoba, Interlake
Industrial minerals geologist	Jim Bamburak	jbamburak@gov.mb.ca	945-6534	Capital region, Cretaceous
Quaternary geologist	Heather Groom	hgroom@gov.mb.ca	945-6546	Aggregate
Geophysicist	Ifti Hosain	ihosain@gov.mb.ca	945-6540	Manitoba, Superior Province
GIS specialist	Greg Keller	grkeller@gov.mb.ca	945-6744	Red River; digital elevation model
Mineral assessment geologist	Peter Leskiw	pleskiw@gov.mb.ca	945-6508	MEAP/Protected Areas
Quaternary geologist	Gaywood Matile	gmatile@gov.mb.ca	945-6530	Red River; digital elevation model
Quaternary geologist	Dr. Erik Nielsen	enielsen@gov.mb.ca	945-6506	Hudson Bay Lowlands; dendrochronology
Dendrochronologist	Scott St. George	sstgeorge@gov.mb.ca	945-6288	Geological Survey of Canada; dendrochronology
GEOSCIENCE INFORMATION SECTION				
Section Head	Paul Lenton	plenton@gov.mb.ca	945-6553	Geological data management and analysis
Database geologist	Glenn Conley	gconley@gov.mb.ca	945-7255	Stratigraphic data files
GIS specialist	Len Chackowsky	lchackowsky@gov.mb.ca	945-8204	GIS
Geological compiler	Dorne Lindal	dlindal@gov.mb.ca	945-0661	1:250 000 compilation series
GIS specialist	Mark Pacey	mpacey@gov.mb.ca	945-4624	GIS; Internet Map Server
CLIENT SERVICES SECTION				
Manager	Monique Lavergne	mlavergne@gov.mb.ca	945-6551	Publications
Library Services	Lori Janower	ljanower@gov.mb.ca	945-6569	Library
Publication Sales	Elaine Hunter	ehunter@gov.mb.ca	945-4154	Publication Sales; library
MIDLAND LABORATORY AND ROCK STORAGE FACILITY				
Manager	Doug Berk	dberk@gov.mb.ca	945-6550	Sample storage and preparation
ADMINSTRATION				
Administrative officer	Diana Kircz	dkircz@gov.mb.ca	945-6558	

Manitoba

Building for the Future

Printed in Canada